The Giant Magellan Telescope

Its instruments and the Brazilian participation

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GMT Brazil Office
FAPESP
GMT

Summary

- Motivation for the Giant Magellan Telescope (GMT)
- ELTs/GMSTs projects and their sites
- GMT consortium and project status
- GMT telescope overview
- GMT instrumentation
- The GMT Brazil Office (GMTBrO) and its instrumentation activities
- Final remarks

Motivation for GMT

Innovation in Astronomy

Progress in astronomy occurs by:

- Technological advancements
- New facilities
- Increase in sample sizes
- Innovative analysis

From David Yong (ANU) "*Chemical enrichment in the early Galaxy*".

Innovation in Astronomy

Progress in astronomy occurs by:

- Technological advancements
- **New facilities**
- Increase in sample sizes
- Innovative analysis

Facilities types:

A. Space-based
B. Surveys
C. Target-oriented

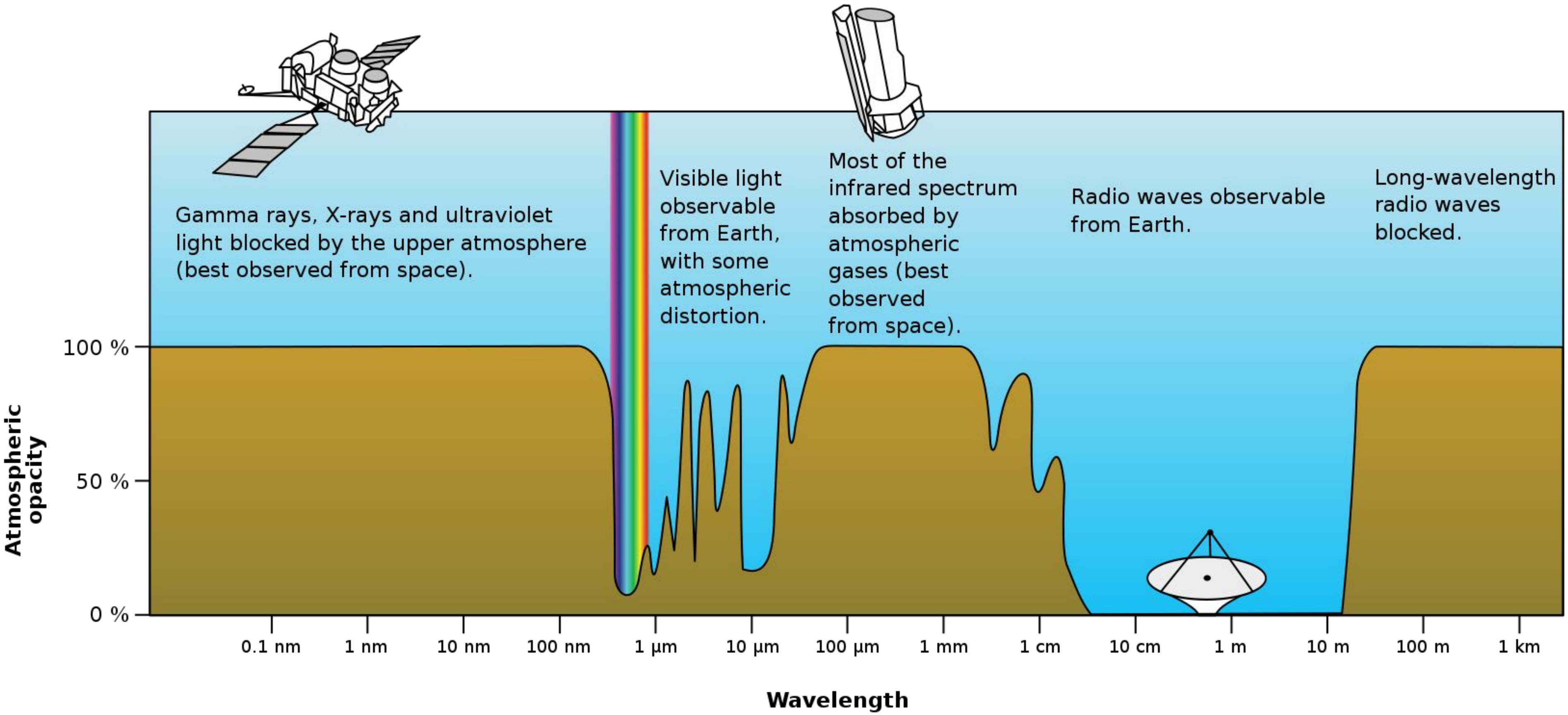
Exciting era in observational astronomy:

- [C] ALMA (2013)
- [A] Gaia (2016)
- [B] S-Plus (2018)
- [B] LIGO (2018)
- [C] EHT (2019)

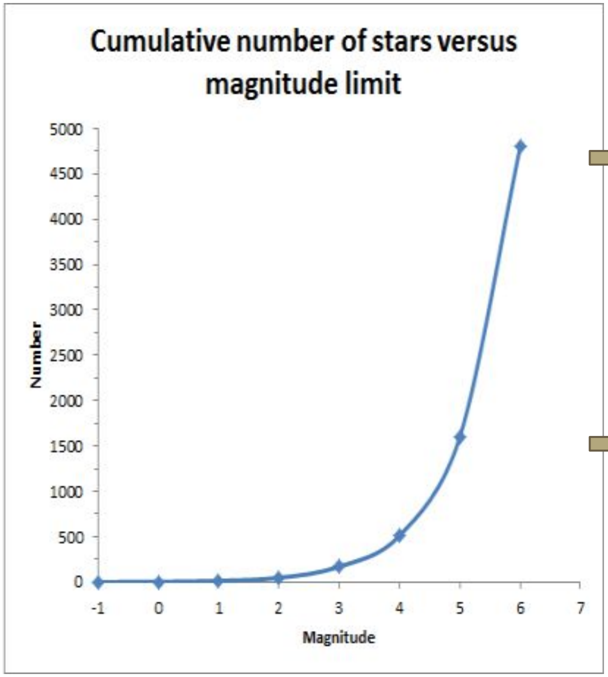
Coming (2020’s):

- [A] JWST
- [A] Euclid
- [A] Plato
- [B] LSST
- [C] **Extreme Large Telescopes (ELTs) or Giant Multi-Segmented Telescopes (GMSTs)**

Telescopes and the atmosphere



Star counting

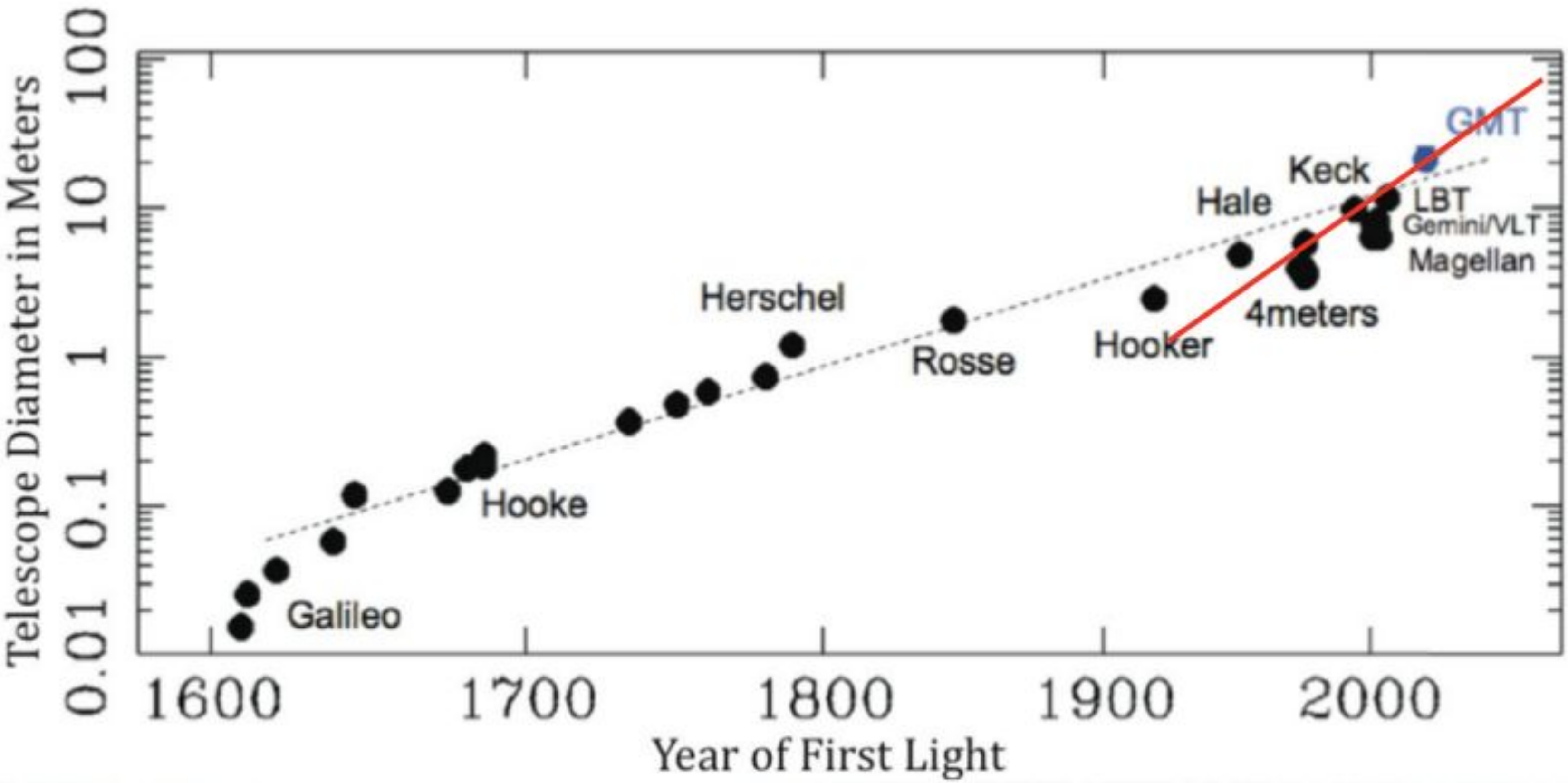


Magnitude	Range	Number of Stars per Range	Cumulative Stars	% Increase in Stars Seen
-1	-1.50 to -0.51	2	2	
0	-0.50 to +0.49	6	8	400%
1	+0.50 to +1.49	14	22	275%
2	+1.50 to +2.49	71	93	423%
3	+2.50 to +3.49	190	283	304%
4	+3.50 to +4.49	610	893	316%
5	+4.50 to +5.49	1,929	2,822	316%
6	+5.50 to +6.49	5,946	8,768	311%
7	+6.50 to +7.49	17,765	26,533	303%
8	+7.50 to +8.49	51,094	77,627	293%
9	+8.50 to +9.49	140,062	217,689	280%
10	+9.50 to +10.49	409,194	626,883	288%
11	+10.50 to +11.49	1,196,690	1,823,573	291%
12	+11.50 to +12.49	3,481,113	5,304,685	291%
13	+12.50 to +13.49	10,126,390	15,431,076	291%
14	+13.50 to +14.49	29,457,184	44,888,260	291%
15	+14.50 to +15.49	85,689,537	130,577,797	291%
16	+15.50 to +16.49	249,266,759	379,844,556	291%
17	+16.50 to +17.49	725,105,060	1,104,949,615	291%
18	+17.50 to +18.49	2,109,295,881	3,214,245,496	291%
19	+18.50 to +19.49	6,135,840,666	9,350,086,162	291%
20	+19.50 to +20.49	17,848,866,544	27,198,952,706	291%

Largest telescopes over time

Typical step size is about x2, about each 40 years.

Factor of ~1000x in diameter since Galileo.

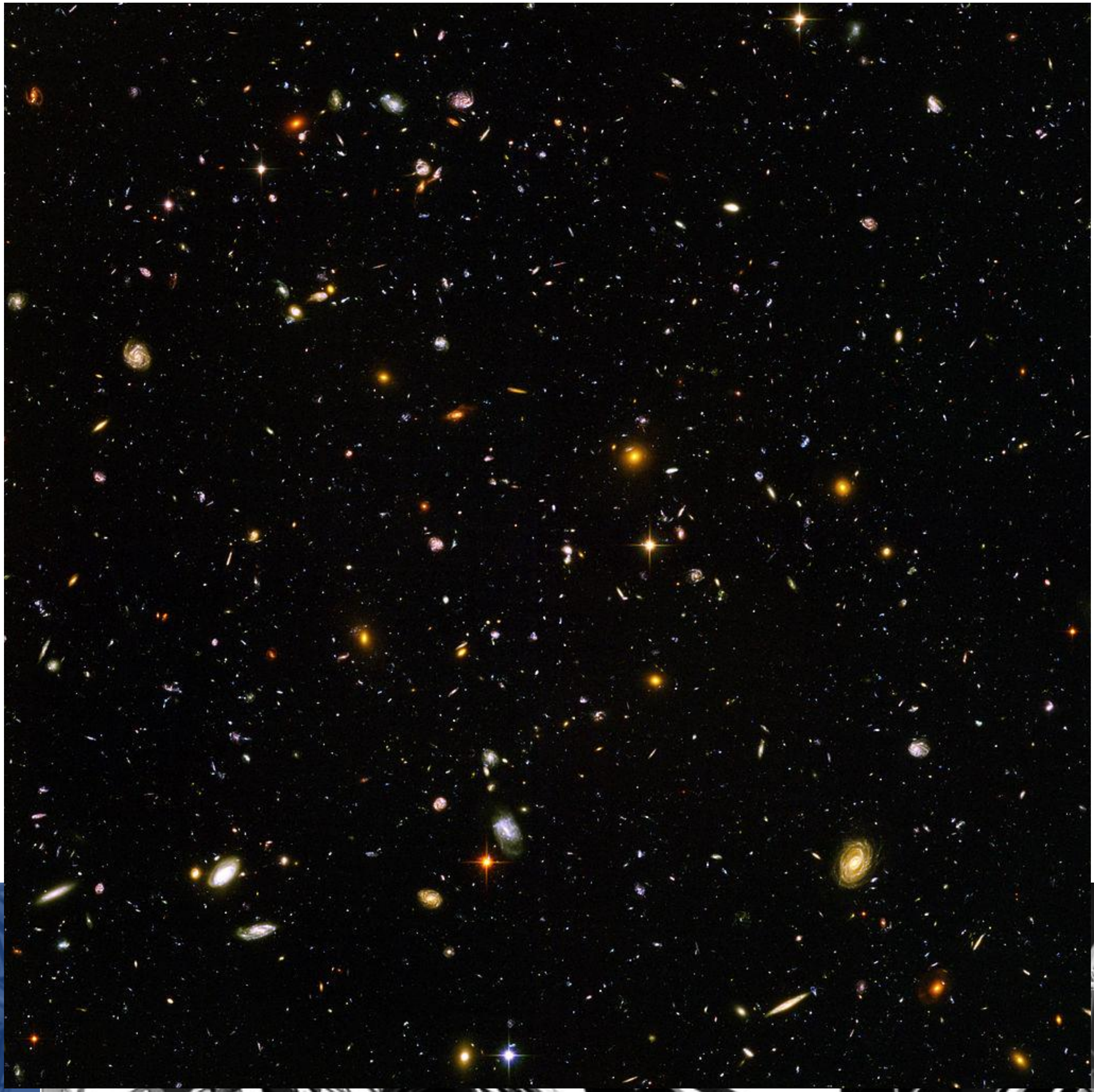


From R. Bernstein

To boldly go...

Discoveries are
"Unscripted"
(Roger Blandford)

- CMB
- Massive BH = radio
- Neutrinos
- Pulsars
- Gamma Ray Bursts
- Dark Matter
- Cosmic Expansion
- Gravitational lenses



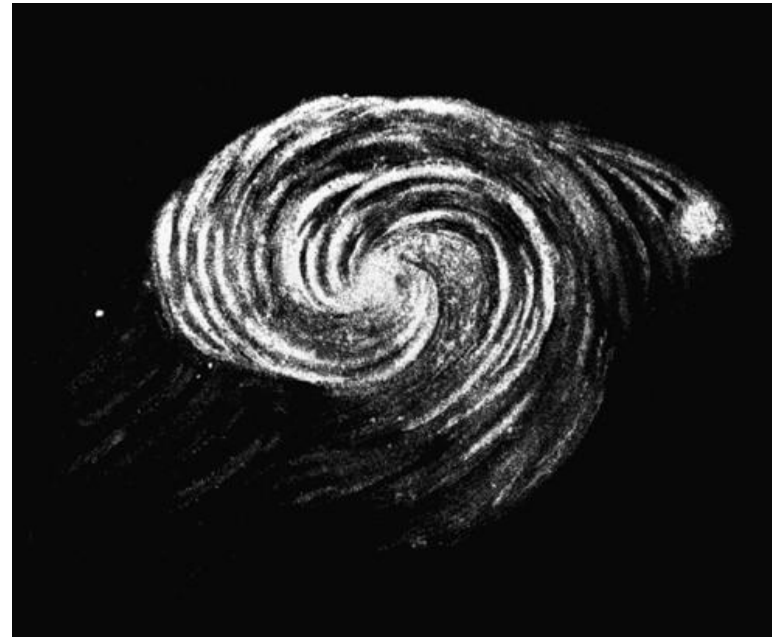
Projects of telescopes

Sizes and dates

- 2-inch (<0.1m) “first telescope”, 1609
- 72-inch (1.8m) Parsonstown, 1845
- 100-inch (2.5m) Hooker telescope, 1917
- 200-inch (5.1m) Hale telescope, 1948
  (...)
- Hubble *space* telescope, 1990

Approx. Budgets

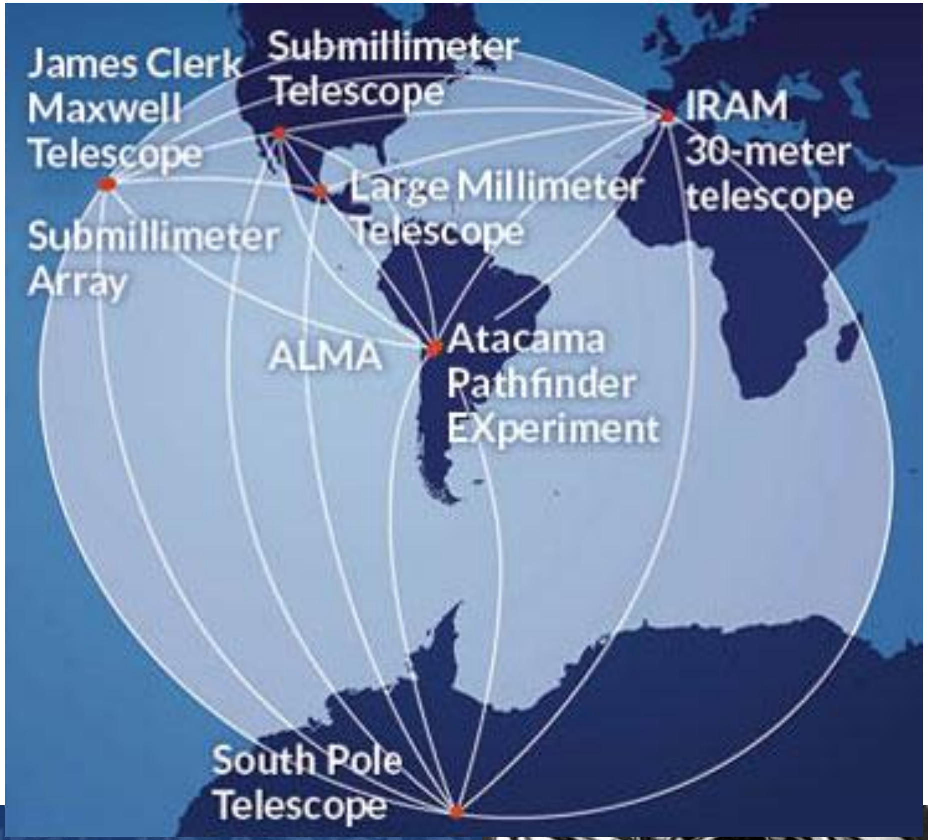
- James Webb ST [1996-2021] = $8.0 bi
- Hubble [1978-1990**] = $1.2 bi in 1986
- GMT [2012-2024] = $1.0 bi

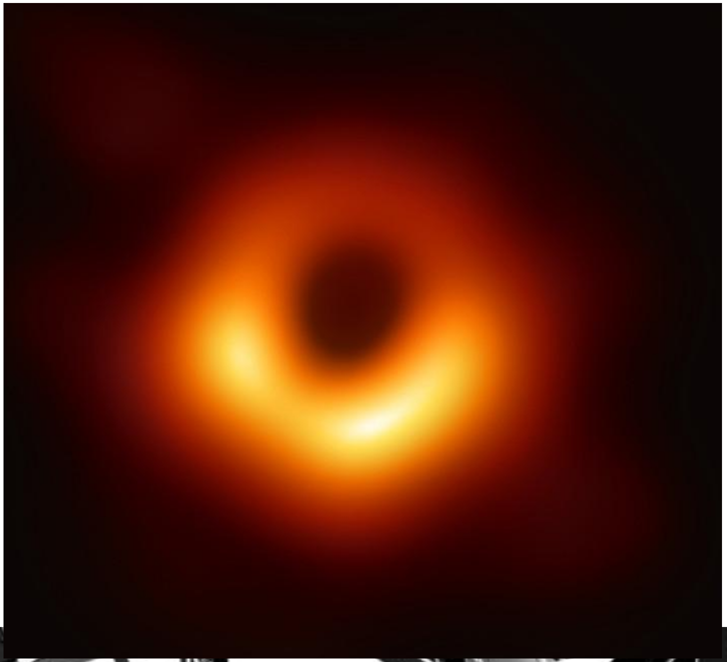


ELTs/GMSTs projects and their sites

Radio *vs* optical telescopes

"Largest telescope ever": EHT





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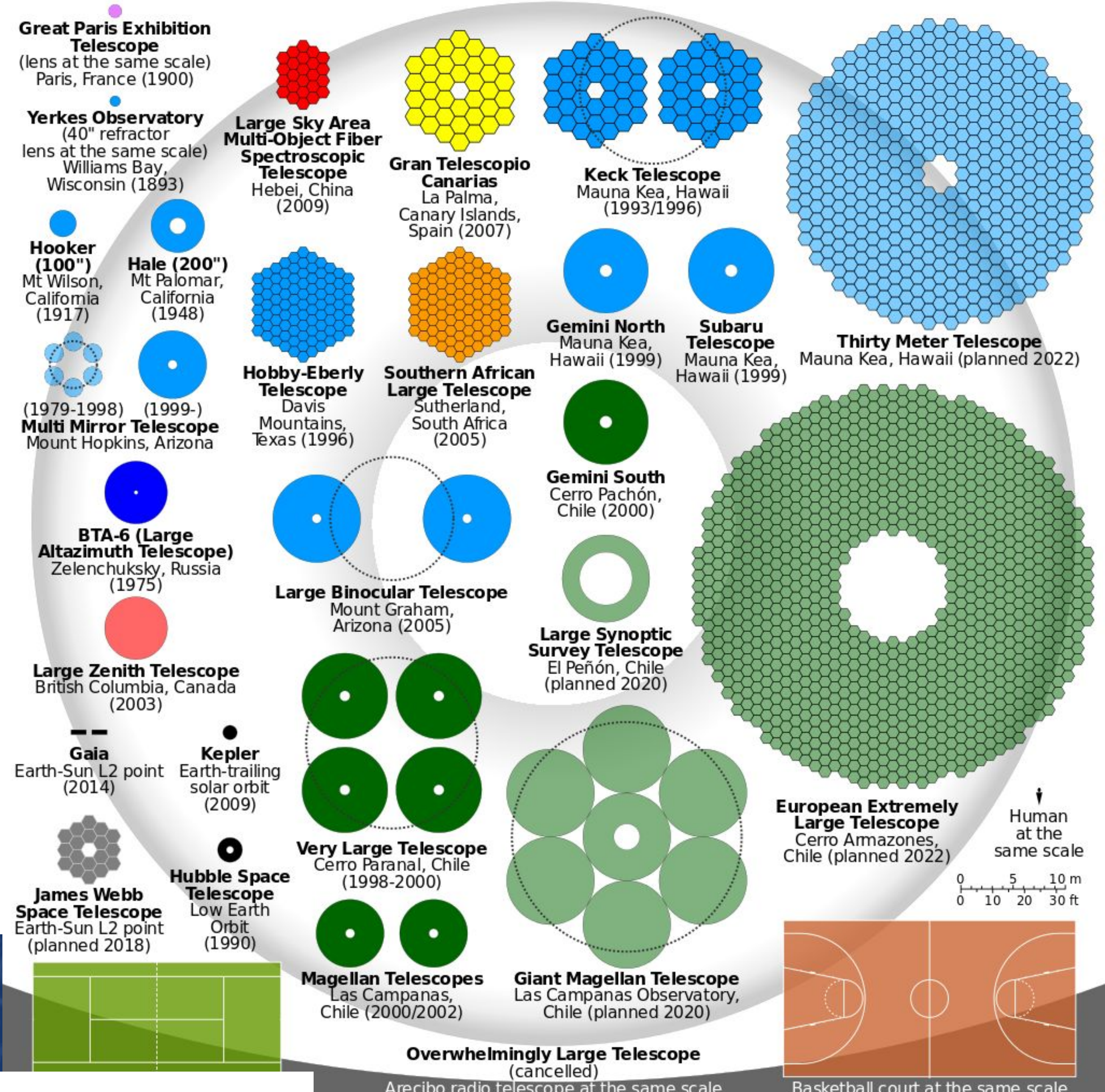
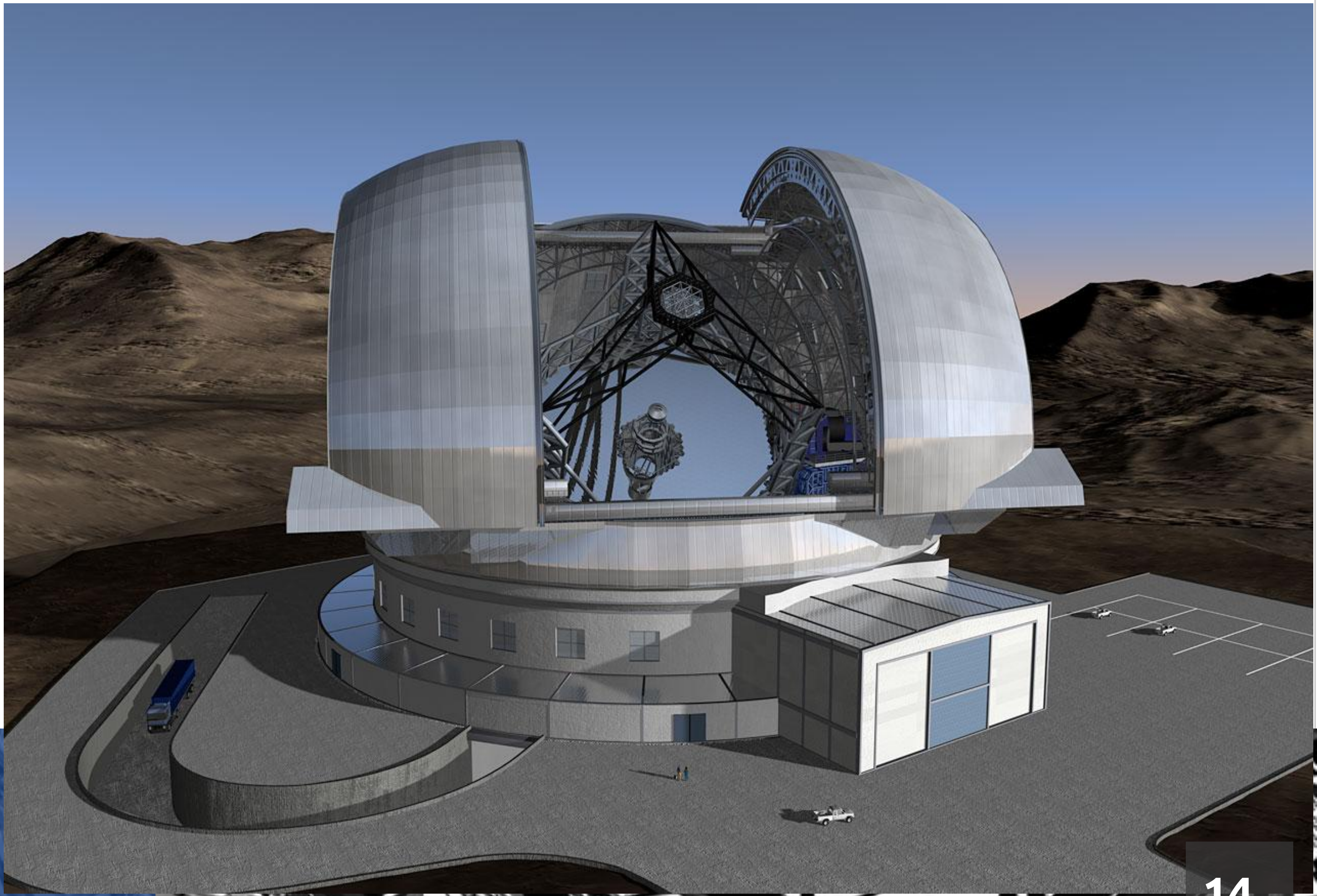


From Wikipedia

E-ELT: European Extremely Large Telescope

D= 39m
A= 978m^2

Location: Chile,
Cerro Armazones



TMT: Thirty Meter Telescope

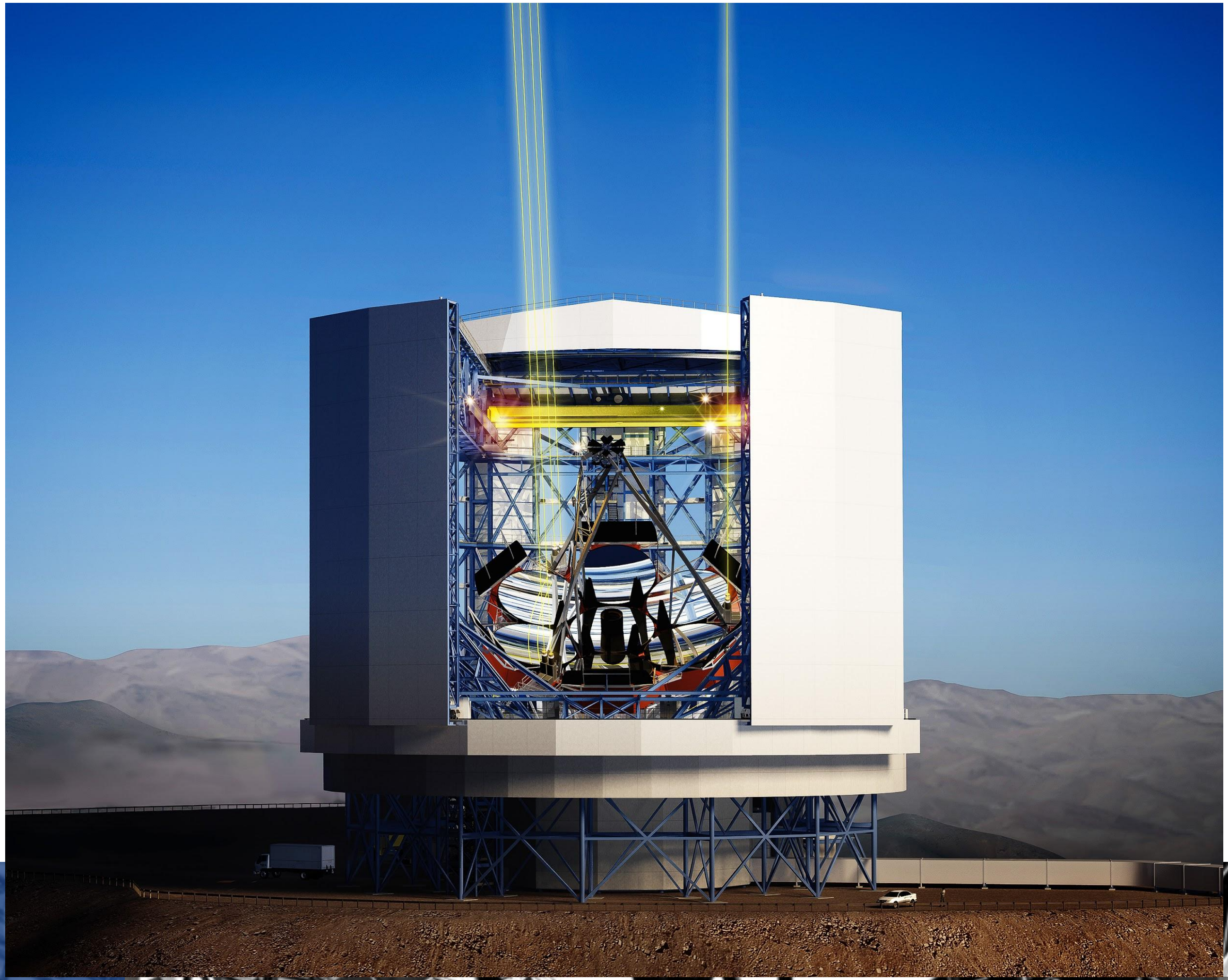
D= 30m
A= 655m^2

Location: Hawaii,
Mauna Kea

GMT: Giant Magellan Telescope

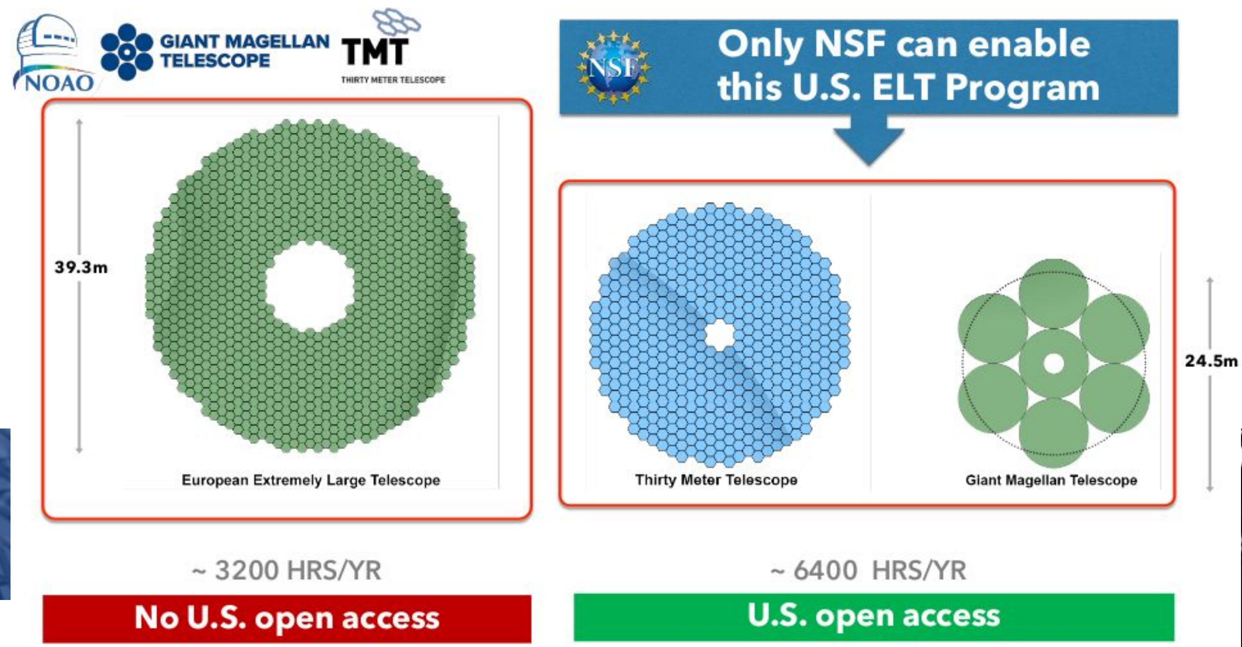
D= 25m
A= 368m^2

Location: Chile,
Cerro Campanas



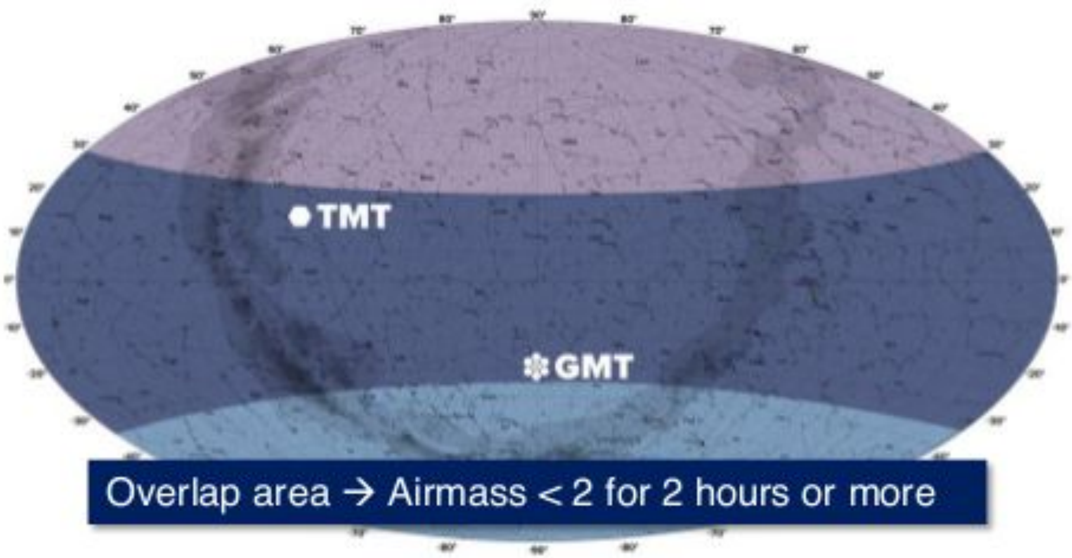
US-ELT Program

https://www.noao.edu/us-elt-program/



From David Silva

US-ELT Program

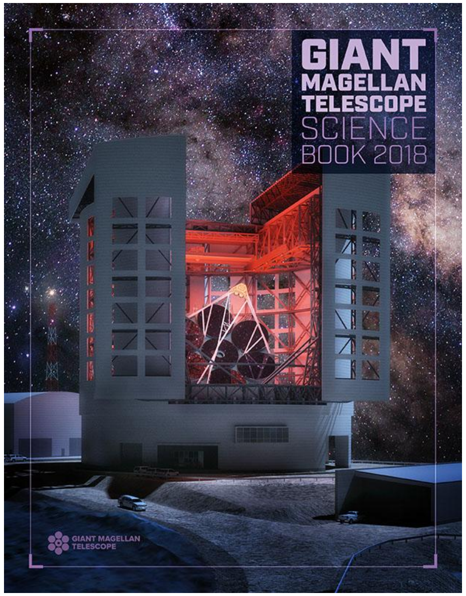


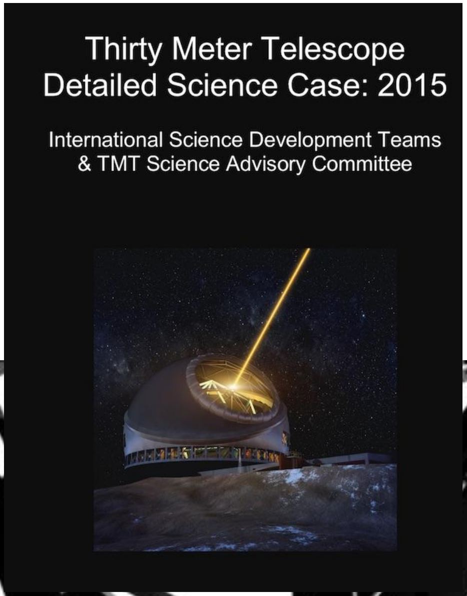
Overlap zone (almost 50% of sky!)

- Joint and/or simultaneous programs on same objects

Separation in longitude (7h)

- Critical for some time-domain phenomena





From David Silva

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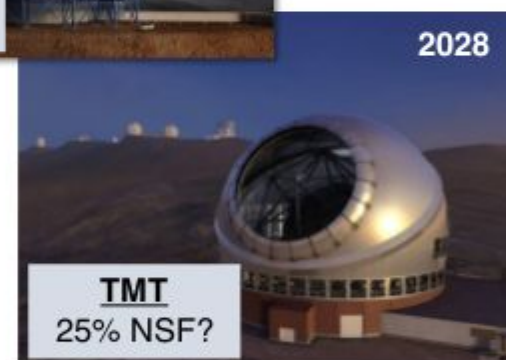
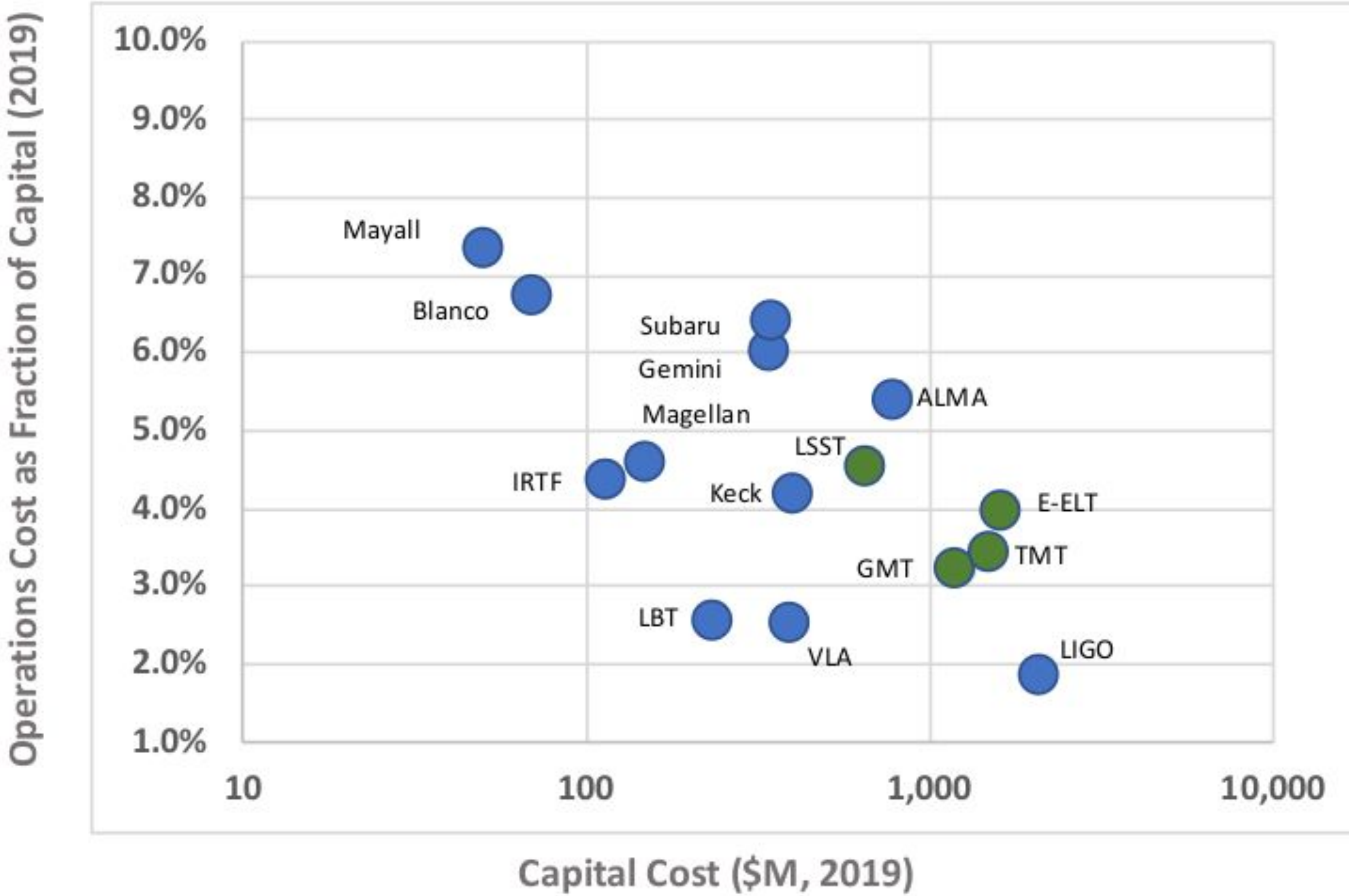
US-ELT Program

ALMA-LIGO scale (~$1B) NSF investments will be needed to realize US open access to the ELTs

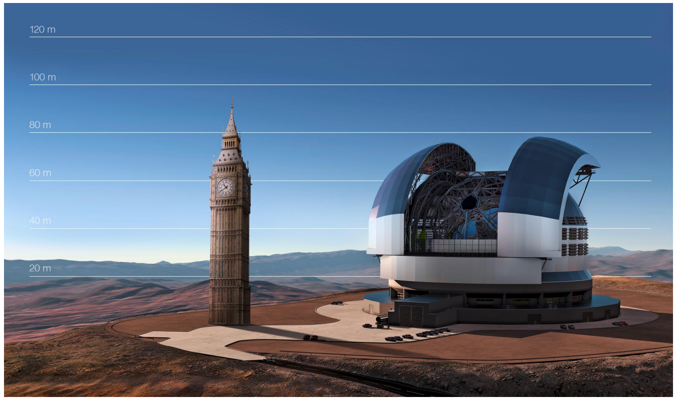


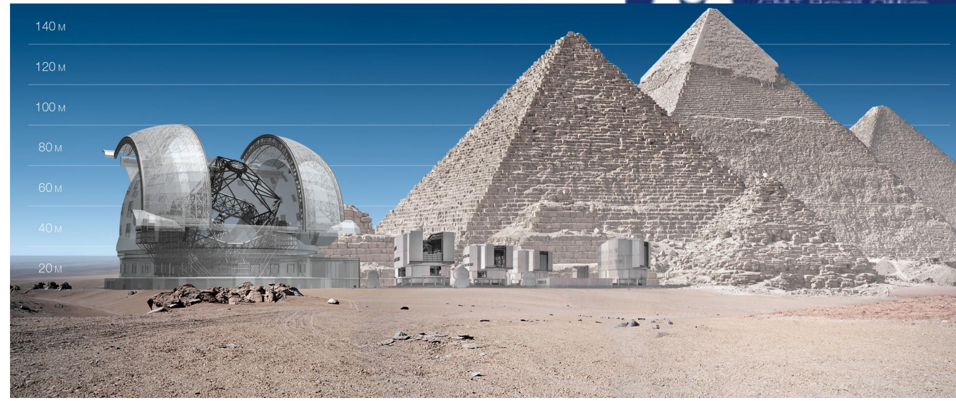
From David Silva

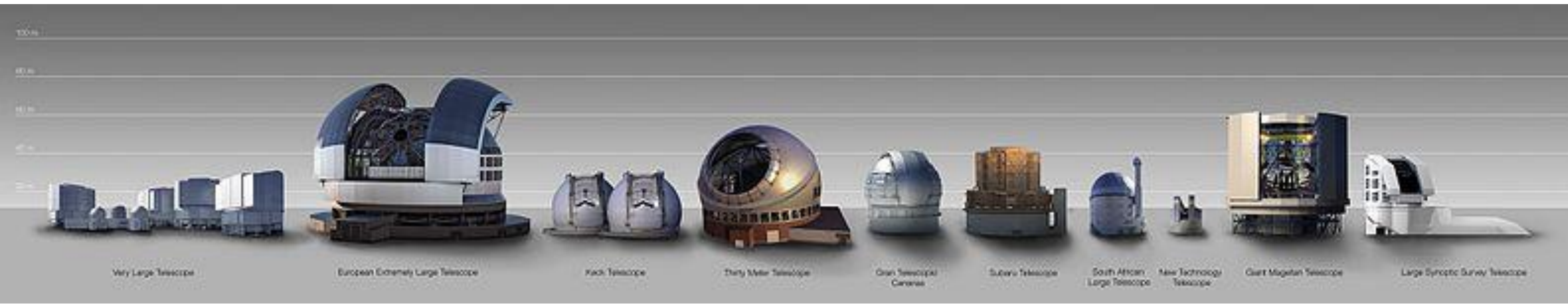
Operations Cost



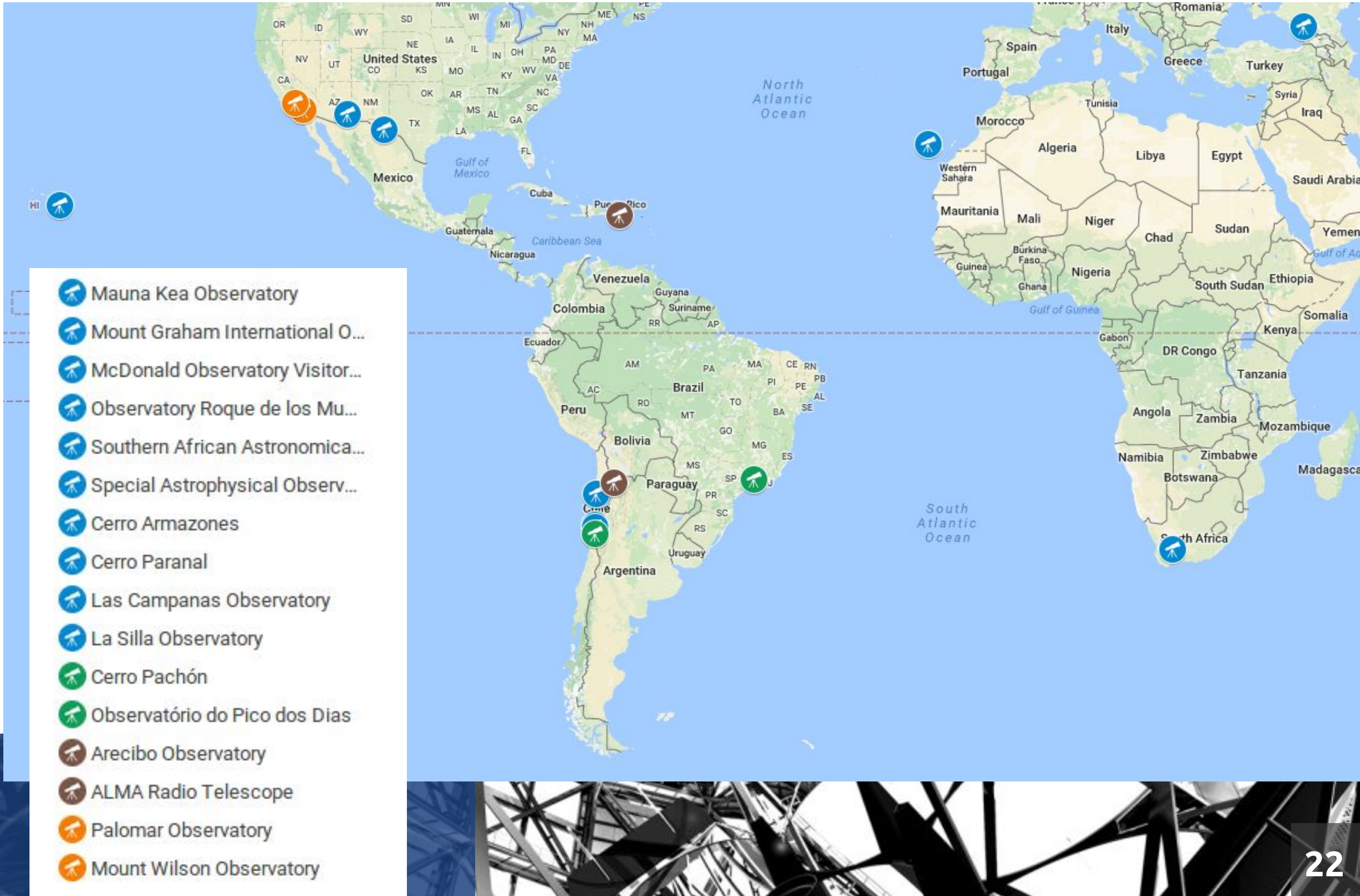
From Robert Goodrich

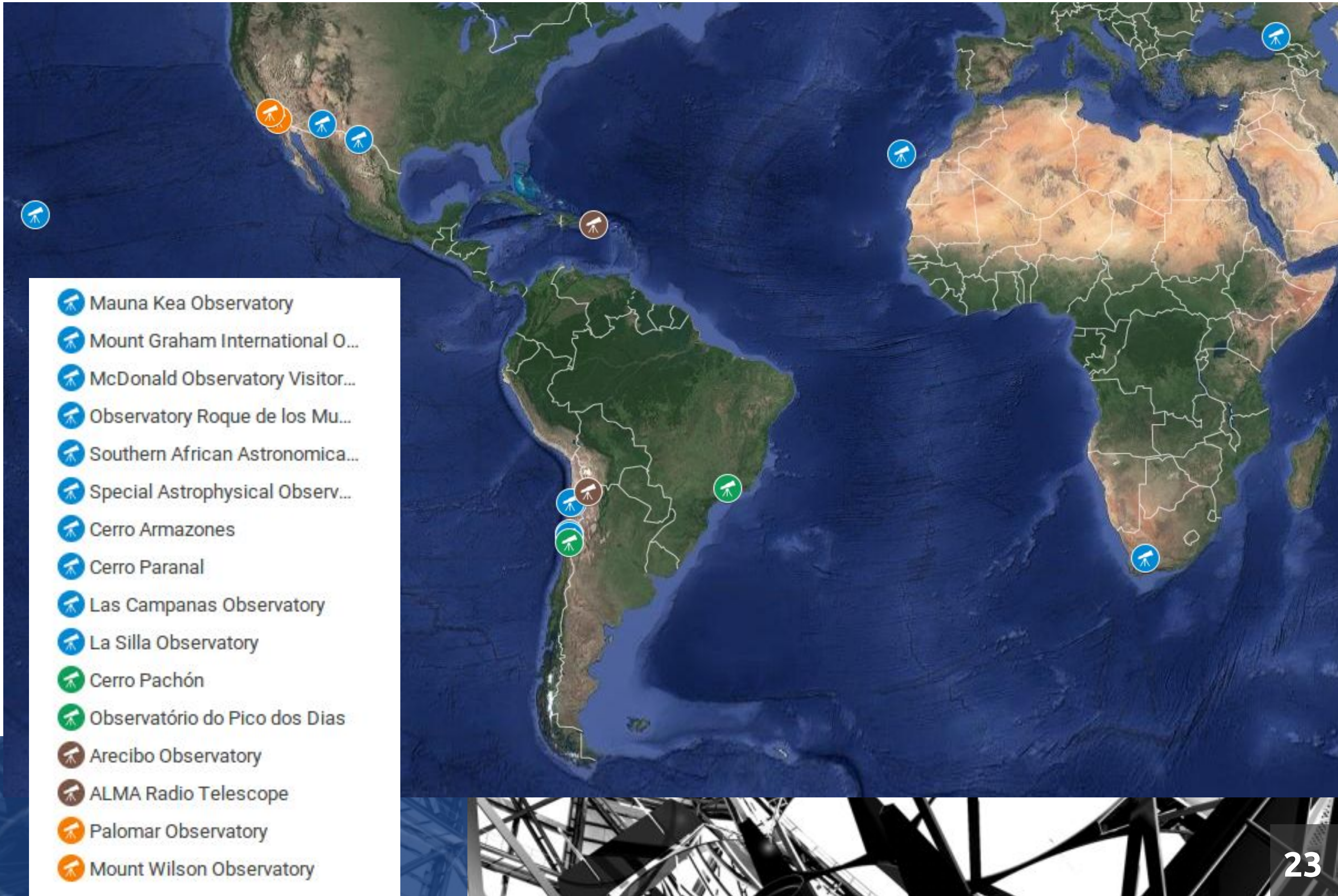

120 m
100 m
80 m
60 m
40 m
20 m


140 M
120 M
100 M
80 M
60 M
40 M
20 M


Very Large Telescope
European Extremely Large Telescope
Keck Telescope
Thirty Meter Telescope
Gran Telescopio Canarias
Subaru Telescope
South African Large Telescope
New Technology Telescope
Giant Magellan Telescope
Large Synoptic Survey Telescope


140 M
120 M
100 M
80 M
60 M
40 M
20 M


Mauna Kea Observatory
Mount Graham International O...
McDonald Observatory Visitor...
Observatory Roque de los Mu...
Southern African Astronomica...
Special Astrophysical Observ...
Cerro Armazones
Cerro Paranal
Las Campanas Observatory
La Silla Observatory
Cerro Pachón
Observatório do Pico dos Dias
Arecibo Observatory
ALMA Radio Telescope
Palomar Observatory
Mount Wilson Observatory
North Atlantic Ocean
South Atlantic Ocean
United States
Mexico
Brazil
Argentina
Africa


Mauna Kea Observatory
Mount Graham International O...
McDonald Observatory Visitor...
Observatory Roque de los Mu...
Southern African Astronomica...
Special Astrophysical Observ...
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Cerro Paranal
Las Campanas Observatory
La Silla Observatory
Cerro Pachón
Observatório do Pico dos Dias
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Palomar Observatory
Mount Wilson Observatory

Calama
San Pedro de Atacama
Mejillones
Antofagasta
Taltal
Chile
Copiapó
Vallenar
La Serena
San Juan
Mendoza
Valparaíso
Santiago

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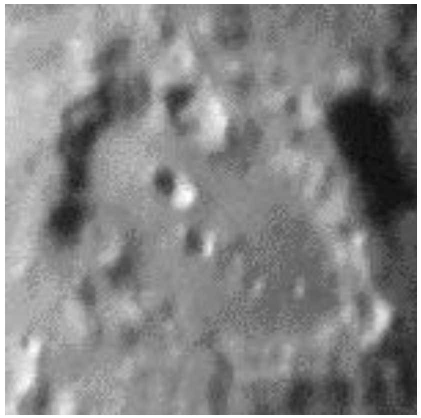
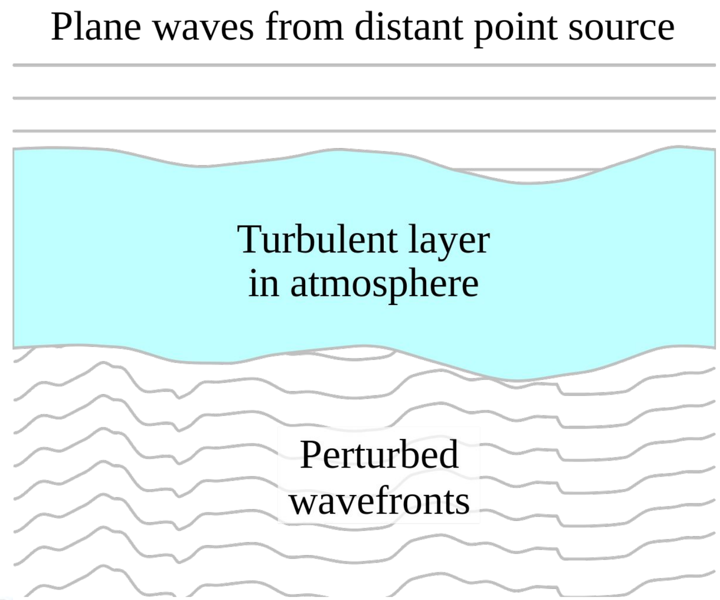
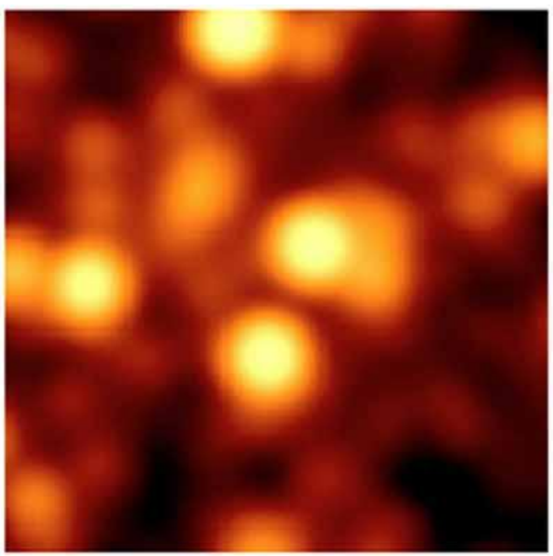
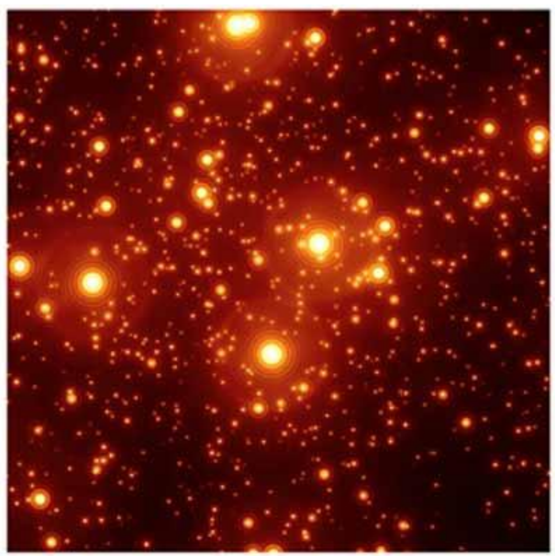
Chile
Copiapó
Vallenar
La Serena
San Juan
Mendoza
Valparaíso
Santiago

Turbulent atmosphere

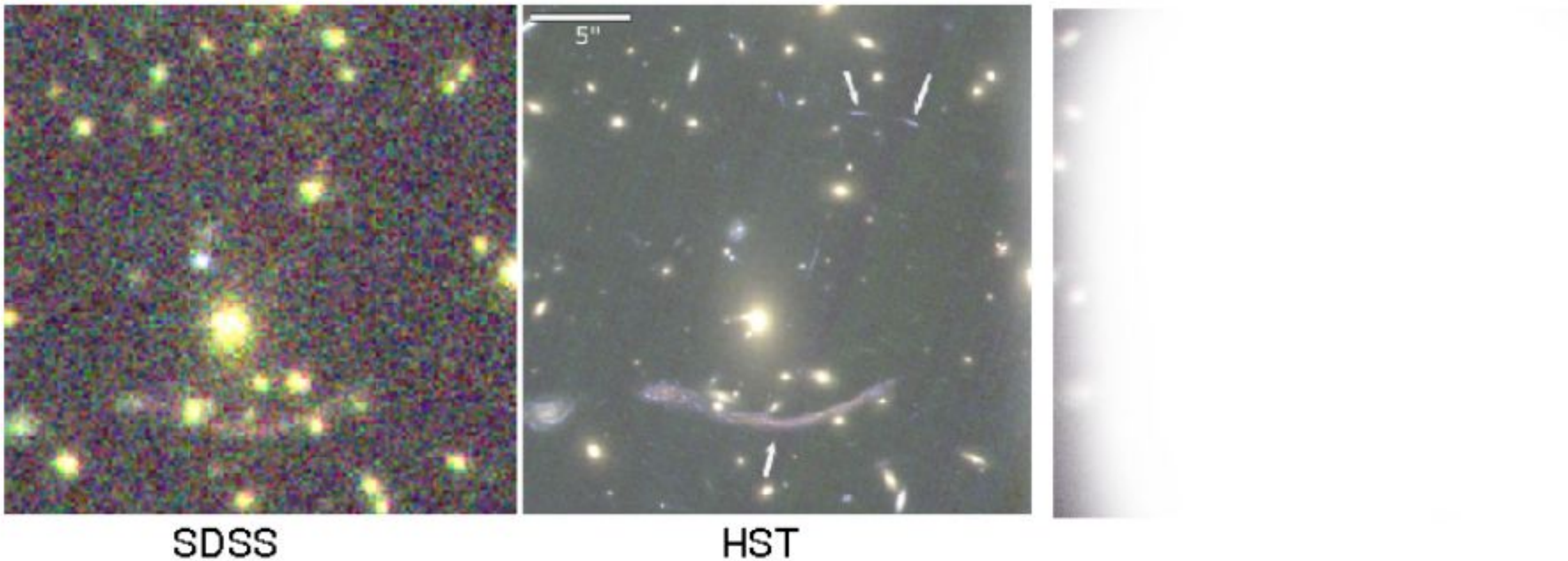








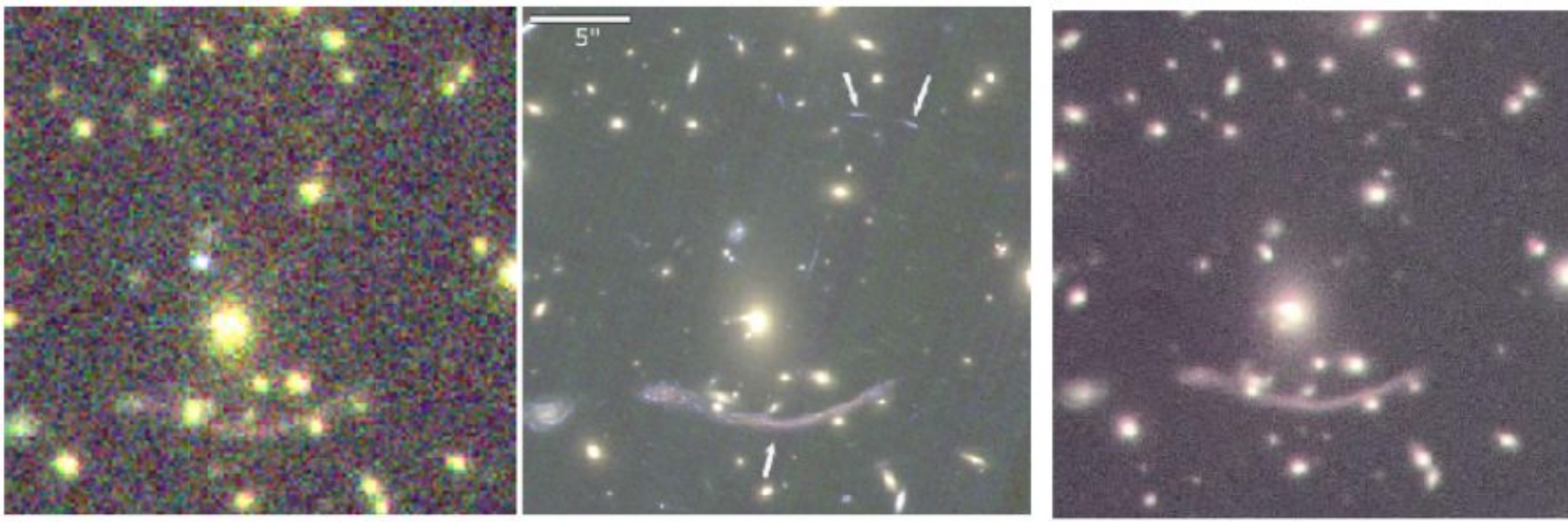
Overcoming the Turbulence



SDSS: Sloan Digital Sky Survey
HST: Hubble Space Telescope

Overcoming the Turbulence = Adaptive Optics (AO)

E.g.: SAM (GLAO) @ SOAR

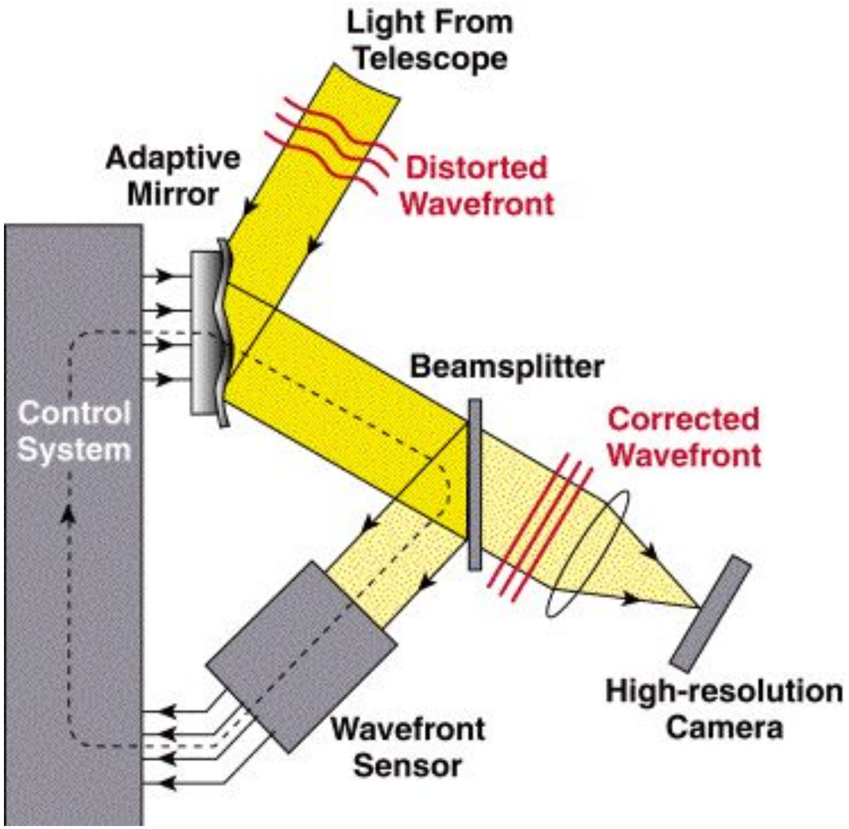


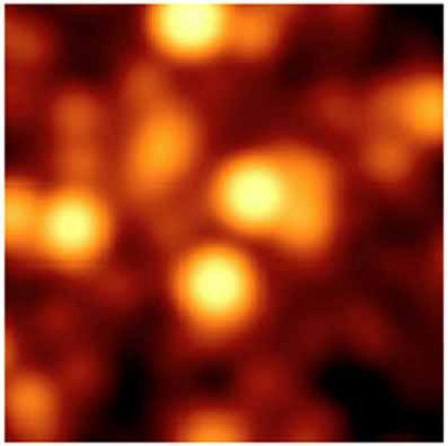
SDSS HST SAM

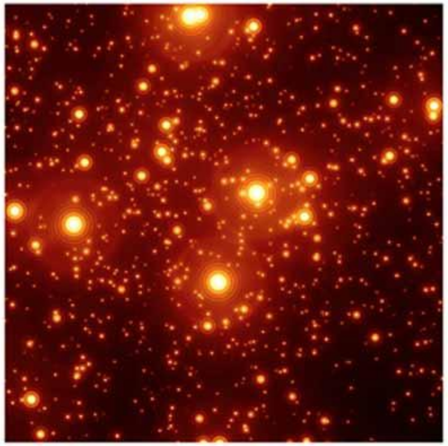
SAM: SOAR Adaptive Module

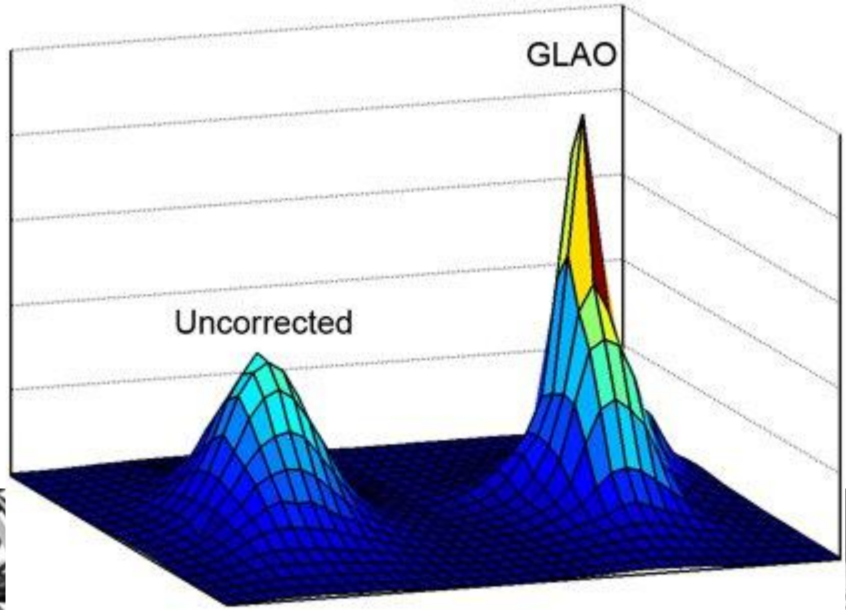
SOAR: SOuthern Astrophysical Research [Telescope]

Adaptive Optics



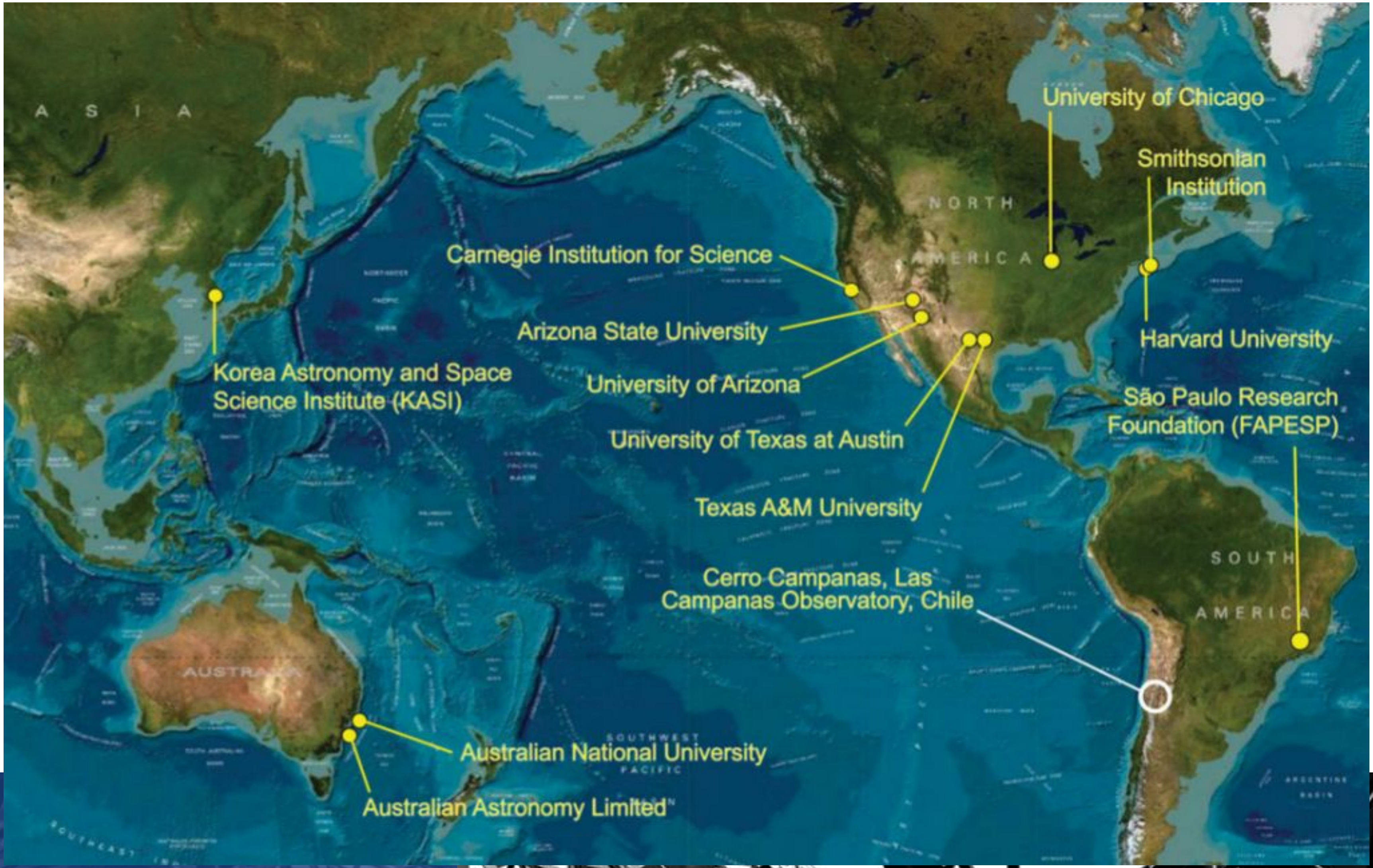






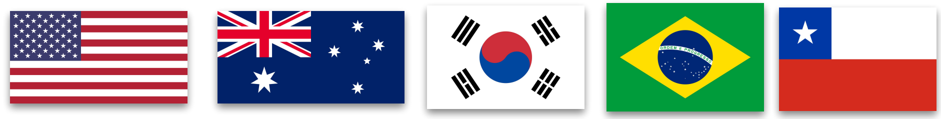
GMT consortium and project status

The partners = GMTO Corporation (2006)



From R. Bernstein

The partners



Arizona State University

Astronomy Australia Limited

Australian National University

Carnegie Institution for Science

FAPESP – The São Paulo Research Foundation

Harvard University

Smithsonian Institution

Korean Astronomy and Space Science Institute

Texas A&M University

The University of Texas at Austin

University of Arizona

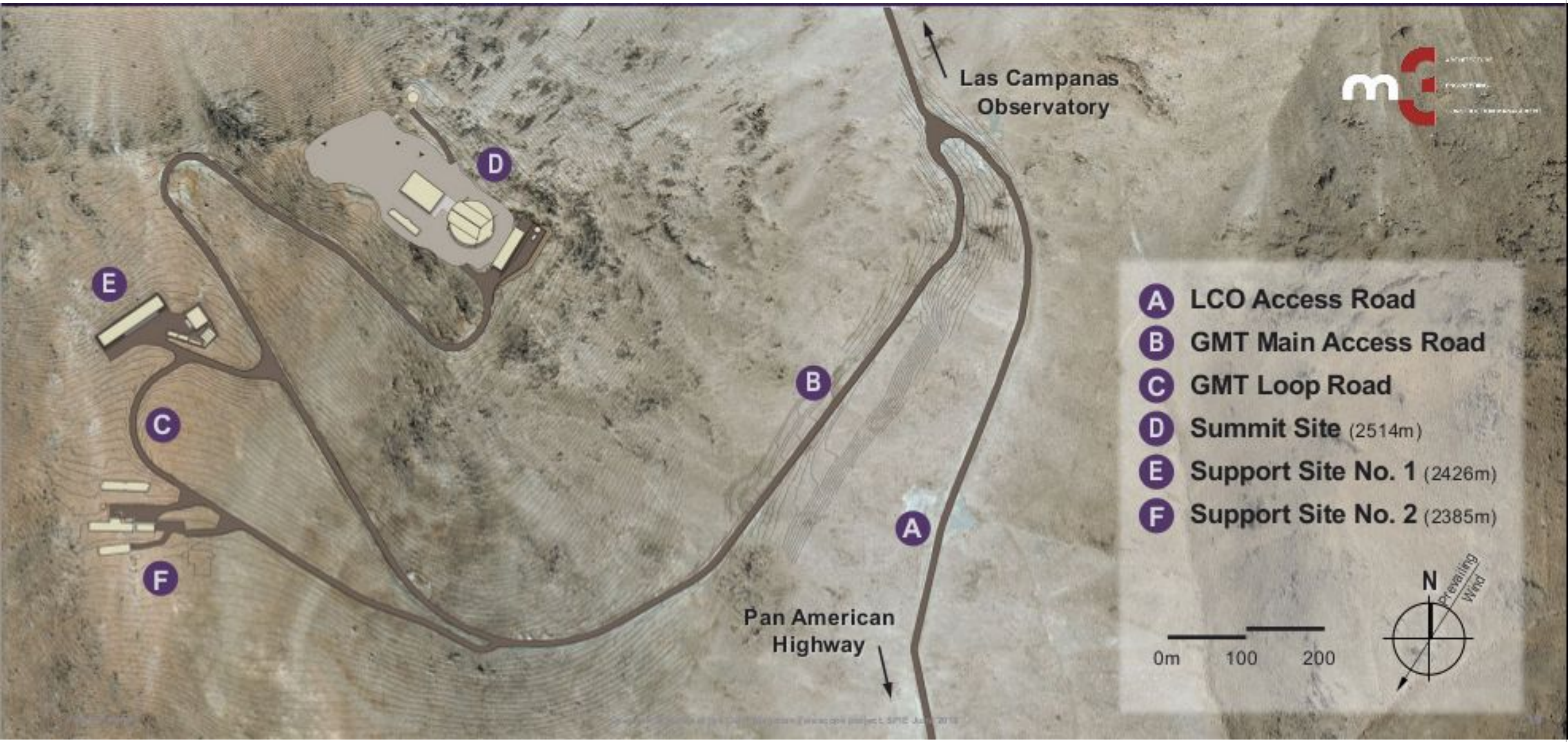
University of Chicago

The partners

GMT Brazil Office
FAPESP
GMT

- KASI Korea
- Astronomy Australia Ltd.
- ASU Arizona State University
- Smithsonian Institution
- FAPESP Sao Paulo, Brazil
- Texas A&M
- Harvard University
- Australian National University
- Carnegie Science
- Arizona
- The University of Texas at Austin
- The University of Chicago

GMT at Las Campanas



GMT at Las Campanas

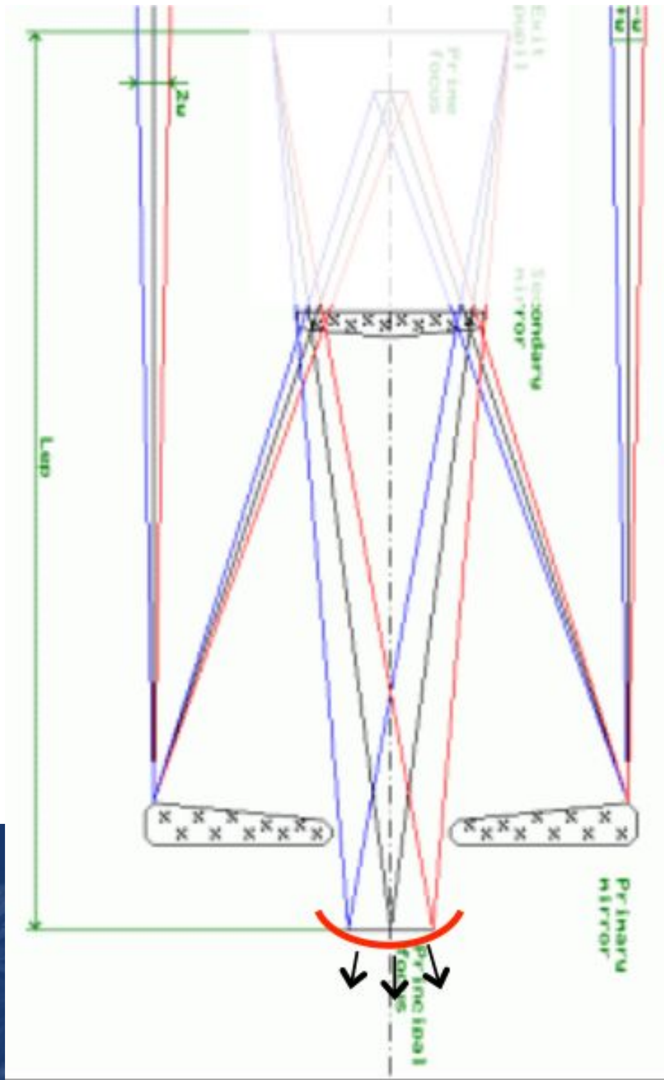
GMT at Las Campanas

GMT at Las Campanas

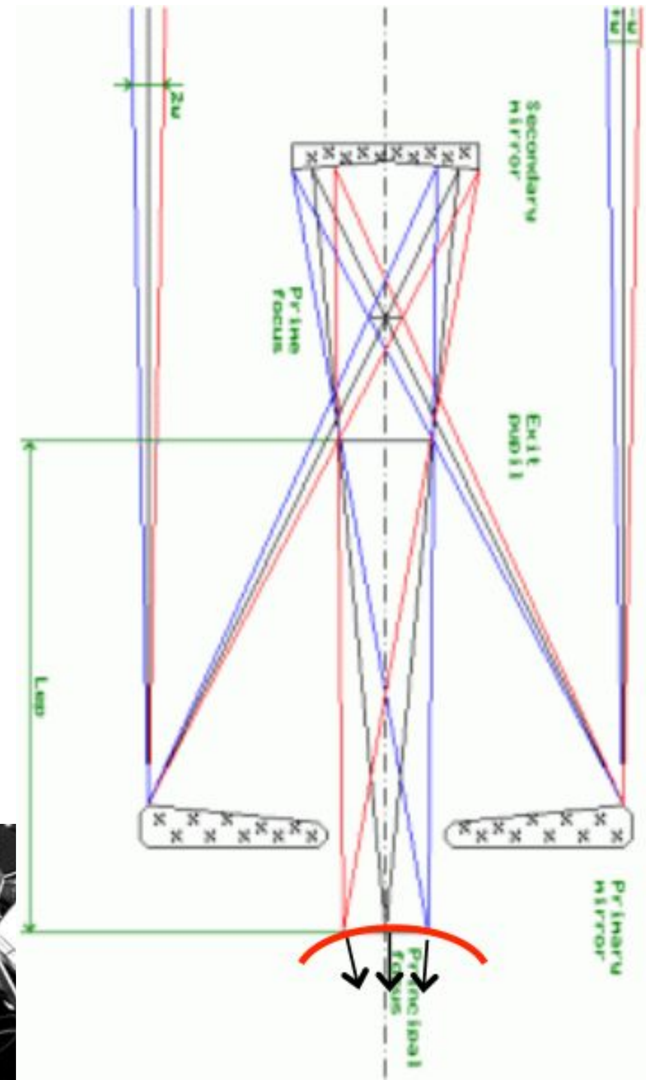
GMT telescope overview

ELTs optics

- **Ritchey-Chrétien** (TMT, Keck, VLT)
- <u>Convex</u> focal plane



- **Gregorian** (GMT, Magellan, LBT)
- <u>Concave</u> focal plane

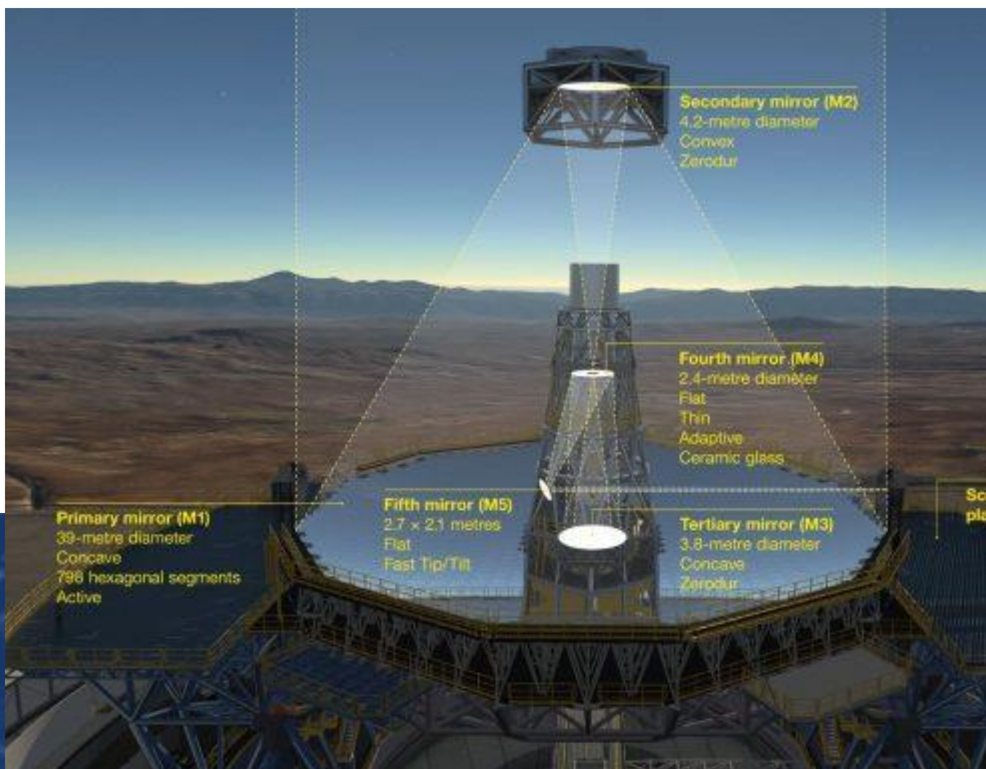


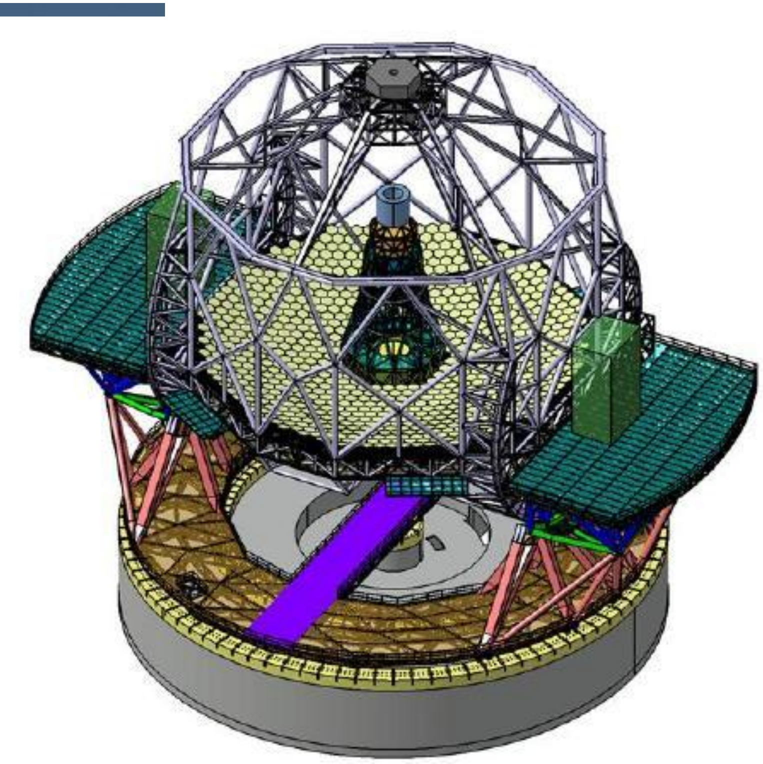
ELTs tech specs

Attribute	GMT	TMT	E-ELT
Aperture	24.5 m	30 m	39.3 m
Collecting Area	368 m^2	655 m^2	978 m^2
Final Focal	**f/8**	f/15	f/17.5
Focal Plane Scale	1.0 mm/arcsec	2.2 mm/arcsec	3.6 mm/arcsec
Field of View	10 arcmin (20 arcmin w/ cor)	10 arcmin (15 arcmin)	7 arcmin (10 arcmin)
Size of 10’ FoV	0.6 meters	1.3 meters	2.0 meters

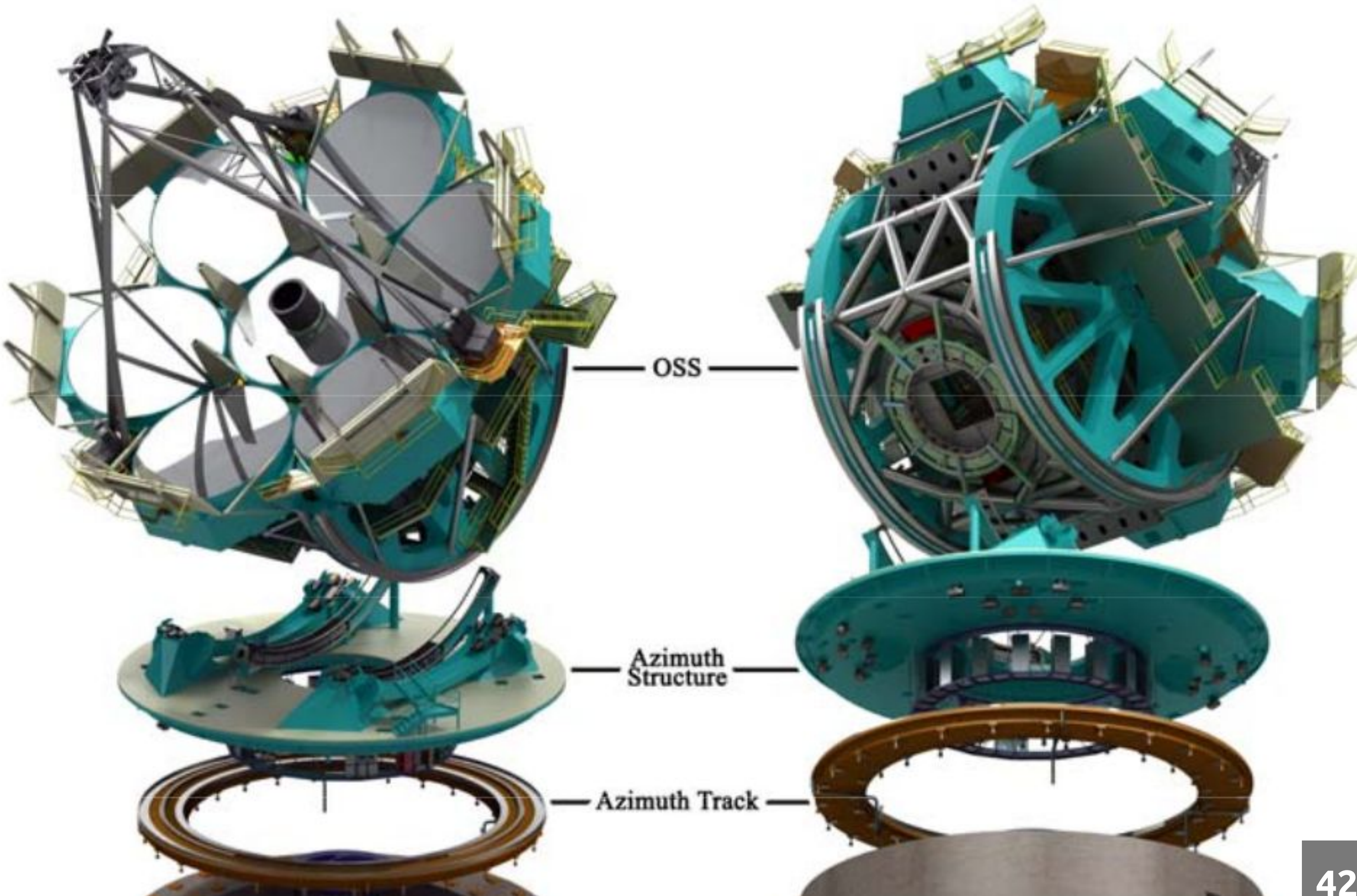
Comparing the ELTs with AO

- GMT: deformable mirror at M2; 2x *warm mirrors*
- TMT: post-focal deformable mirror. 2x *warm mirrors* + 10x cold mirrors
- ELT: deformable mirror at M4; 5x *warm mirrors*



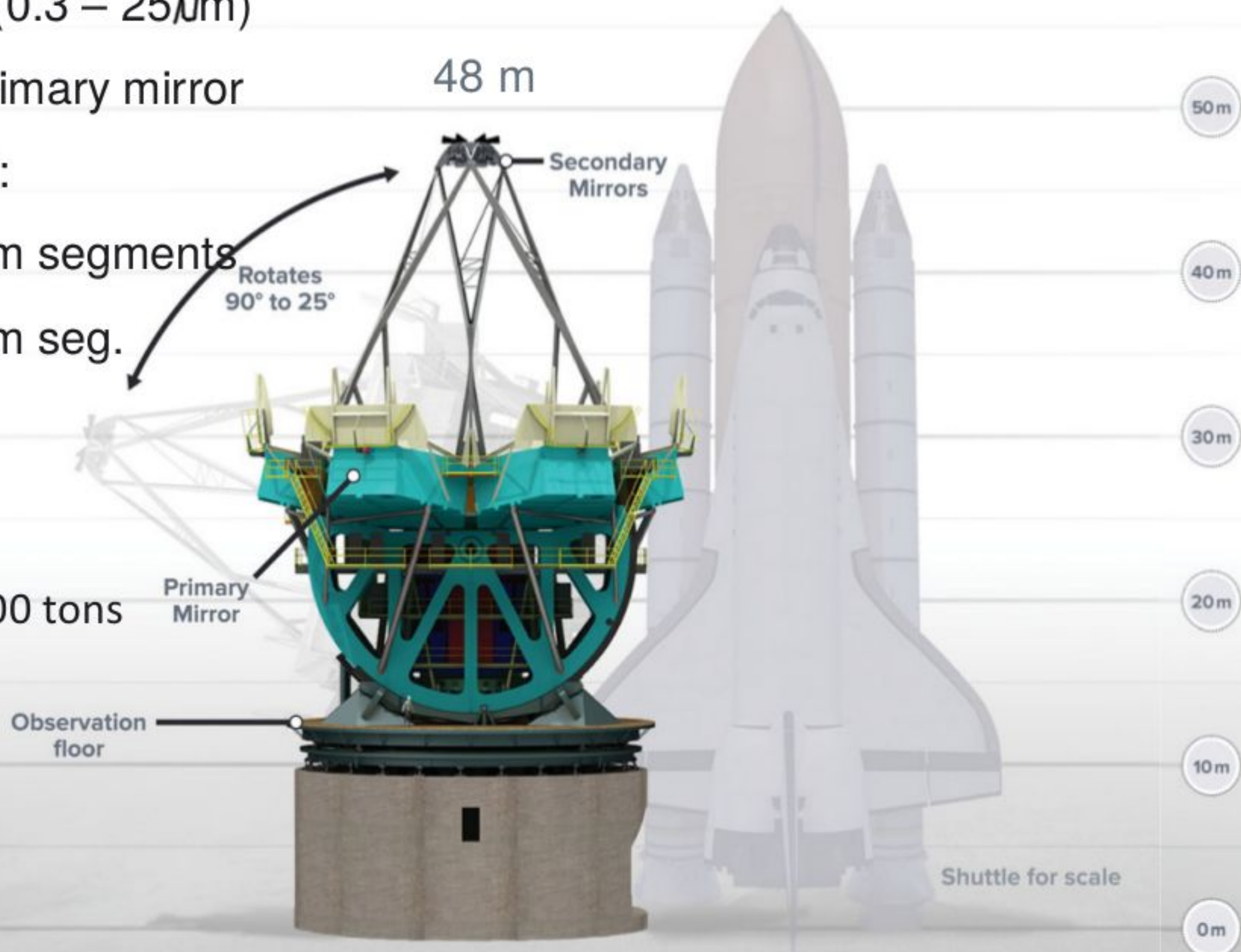


The Giant Magellan Telescope

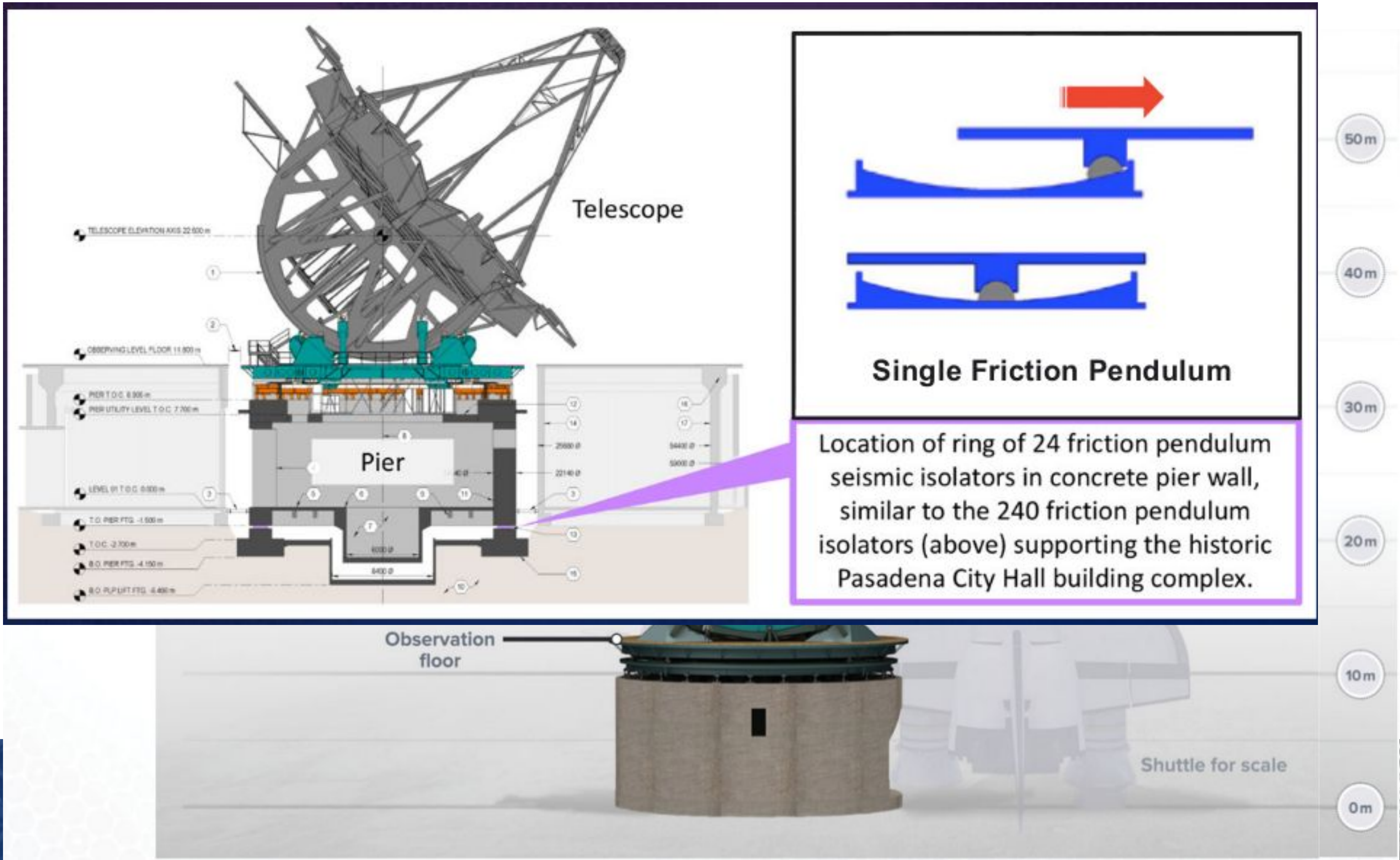


The Giant Magellan Telescope

- Optical to Infrared (0.3 – 25µm)
- 25.4 m diameter primary mirror
- Double segmented:
  - M1: seven 8.4m segments
  - M2: seven 1.1m seg.
- Telescope mass: 1,400 tons

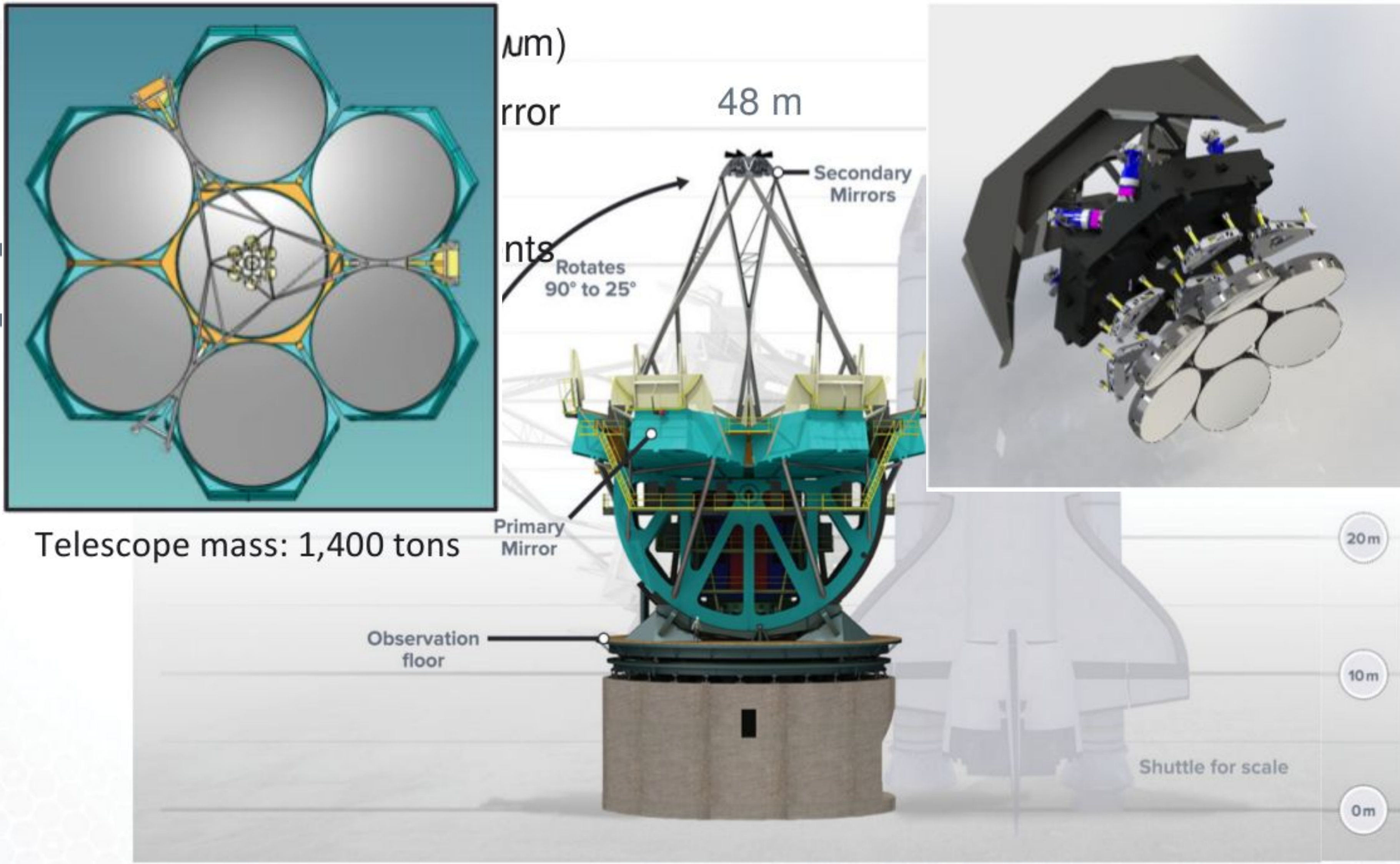


The Giant Magellan Telescope



The Giant Magellan Telescope

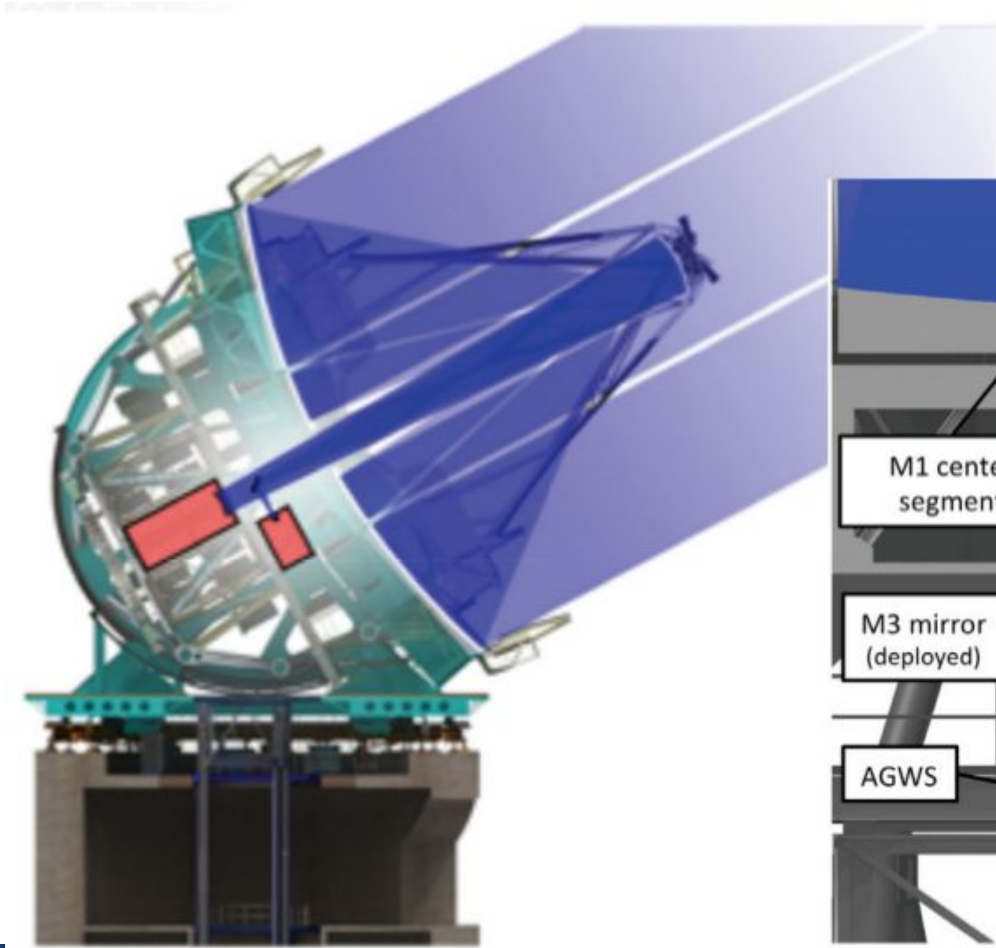
- µm)
- rror
- nts

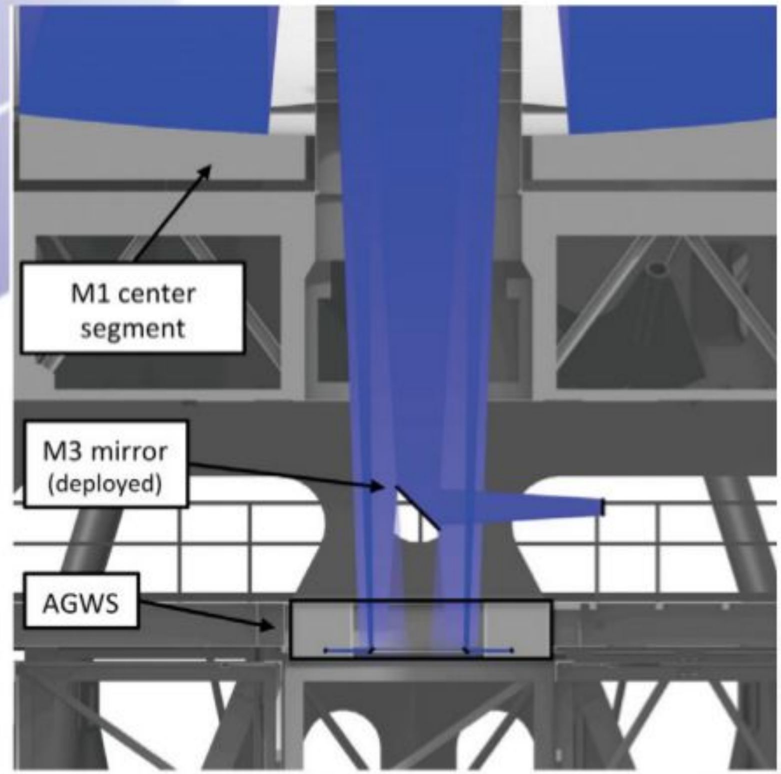


- Telescope mass: 1,400 tons

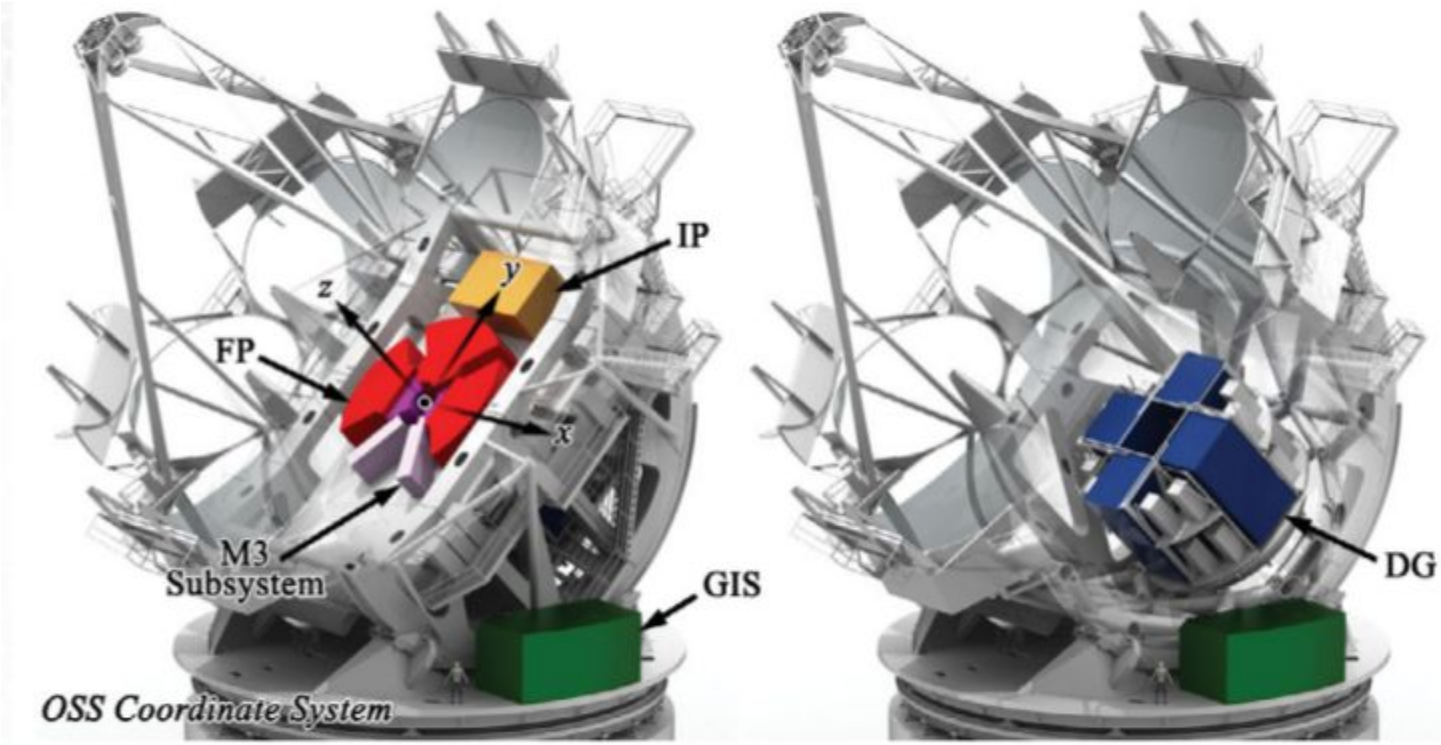
GMT Instrumentation

The Giant Magellan Telescope



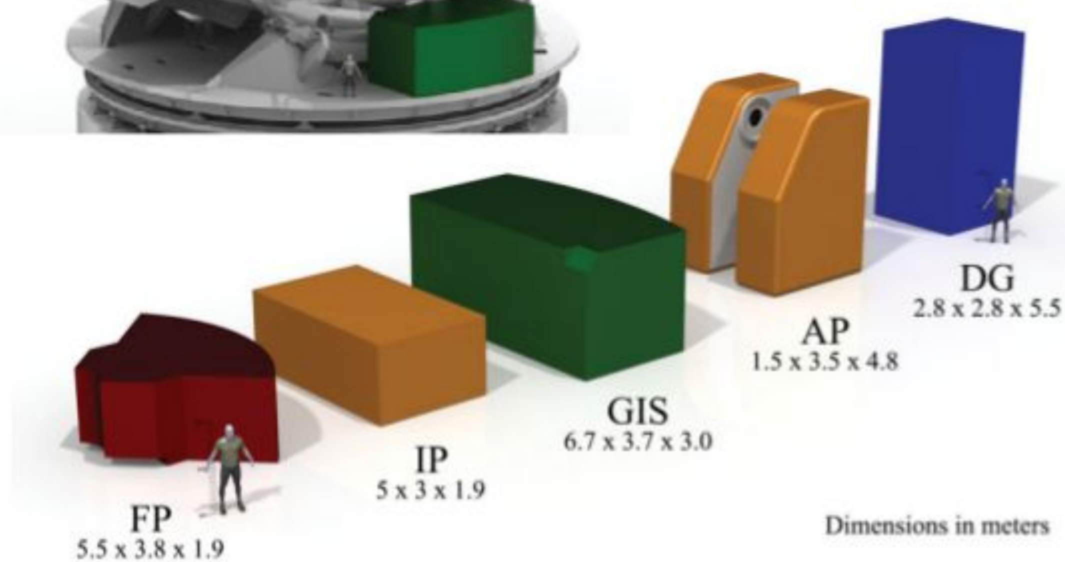


The GMT instrumentation

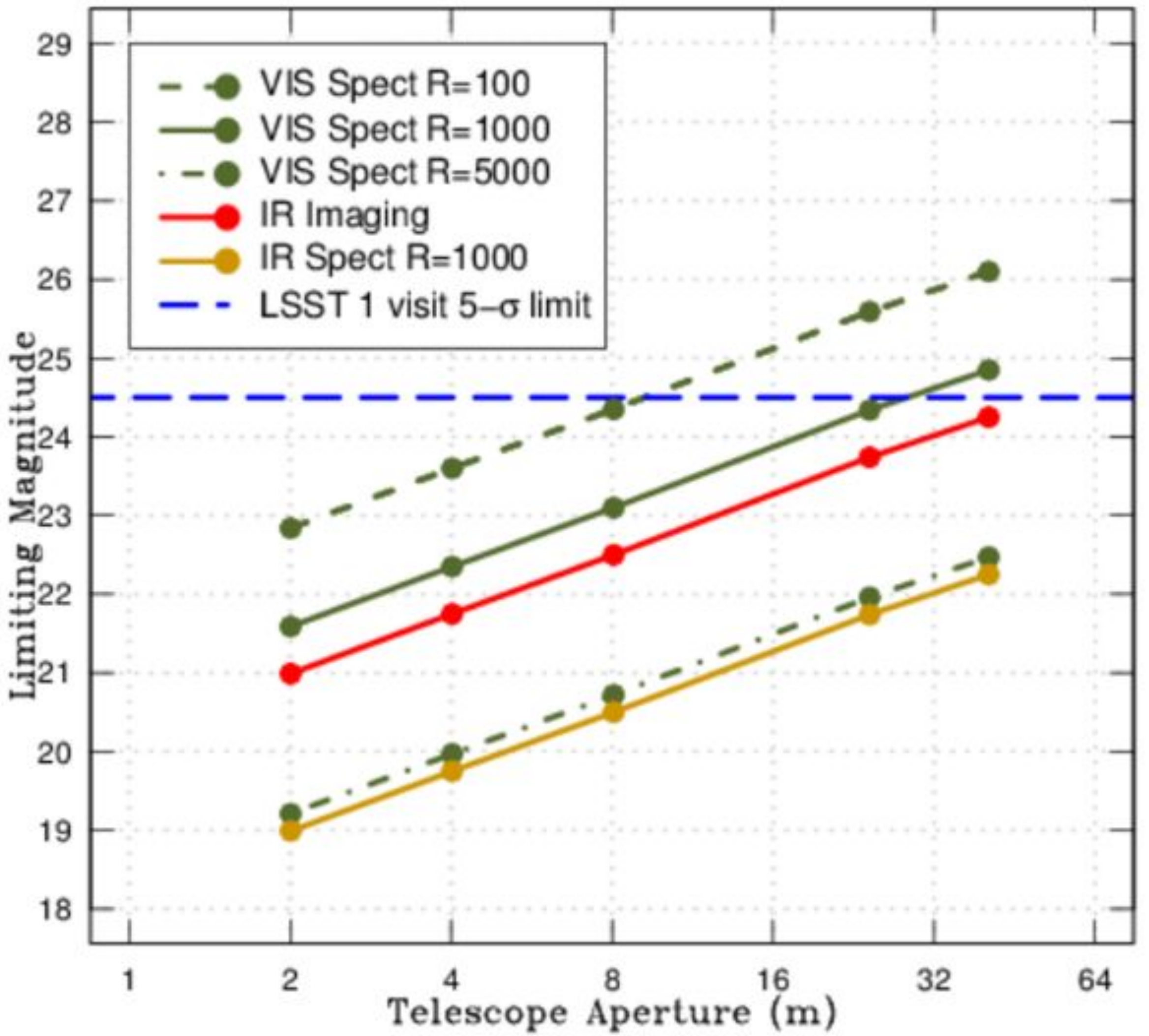


10 mounted instruments

- Folded Port (FP)
- Instrument Platform (IP)
- Gravity Invariant Station (GIS)
- Auxiliary Port (AP)
- Direct Gregorian (DG)



Sensitivity as a function of aperture



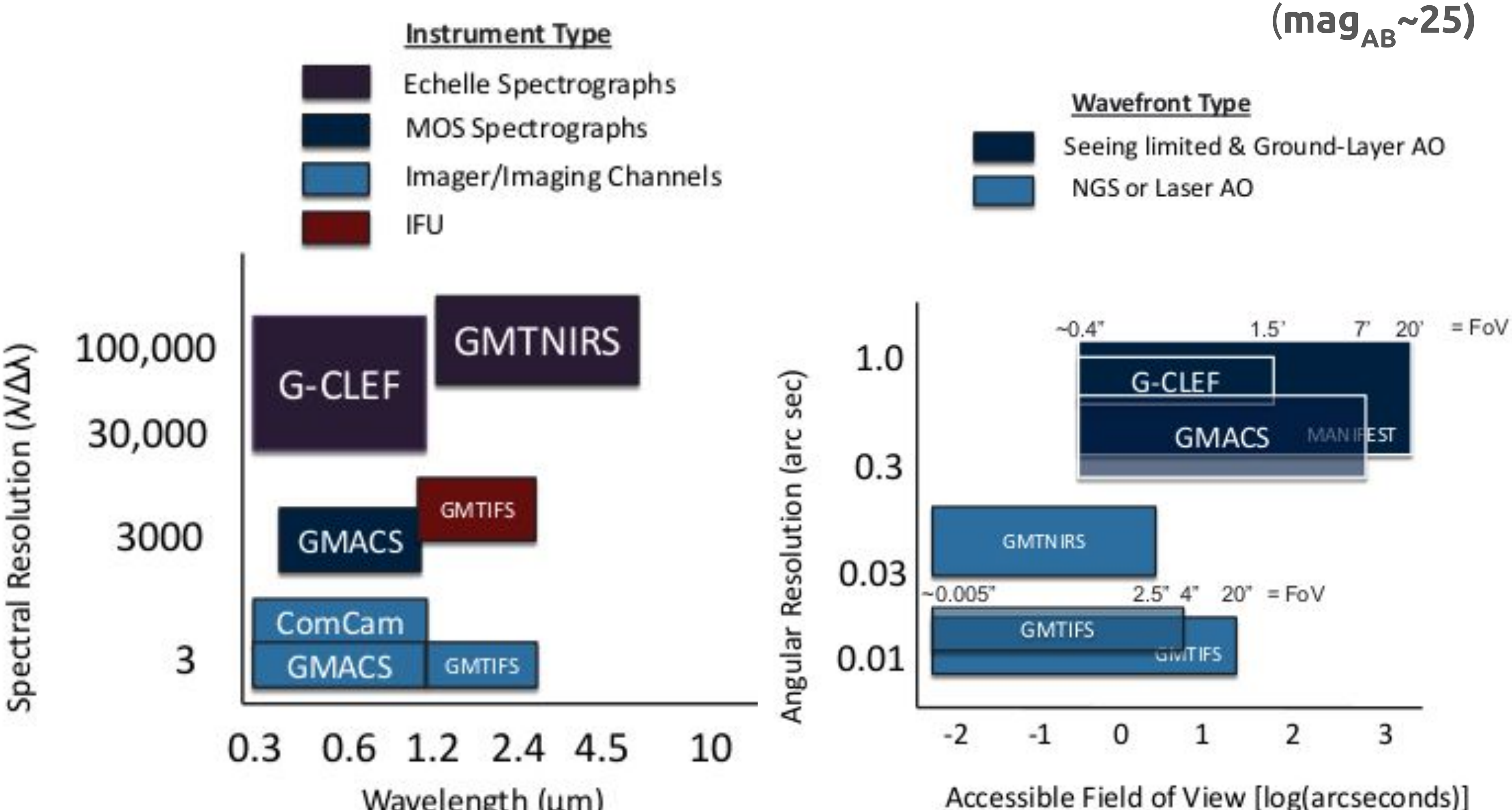
Instrumentation

Instrument	Function	λ Range (μm)	Resolution	Field of View
G-CLEF	Optical High Resolution Spectrograph / PRV	0.35 – 0.95	20 – 100 k	7 x 1” fibers
GMACS	Optical Multi-Object Spectrograph	0.32 – 1.0	1000 – 6000	40 – 80 arcmin^2
GMTIFS	NIR AO-fed IFU / Imager	0.9 – 2.5	4000 – 10,000	10 / 400 arcsec^2
GMTNIRS	JHKLM AO-fed High Resolution Spectrograph	1.2 – 5.0	50 – 100 k	Single Objec
MANIFEST*	Facility Robotic Fiber Feed	0.36 – 1.0	-	300 arcmin^2
ComCam	GLAO Commissioning Camera	0.37 – 0.90	-	40 – 80 arcmin^2

*MANIFEST is included in the instrumentation program and budget.

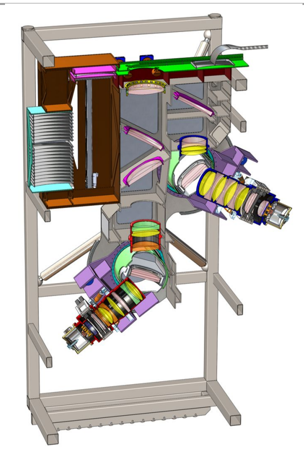
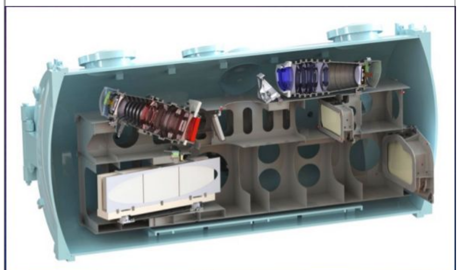
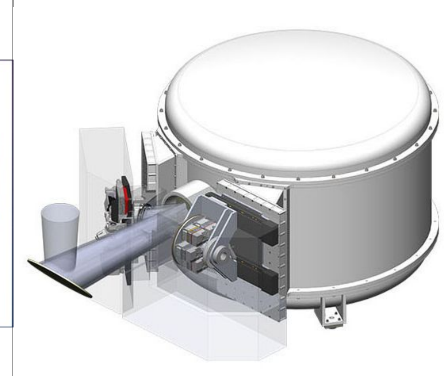
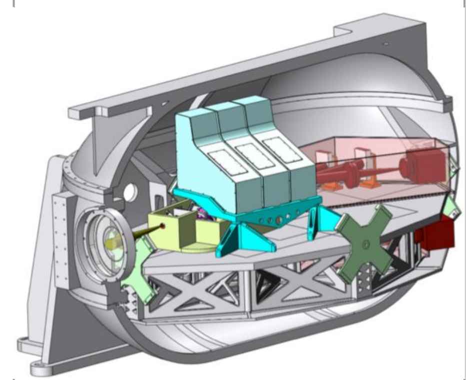
The GMT instrumentation

GMT will be able to take **spectra** of nearly any object in the **LSST deep catalog.** **(mag_{AB}~25)**

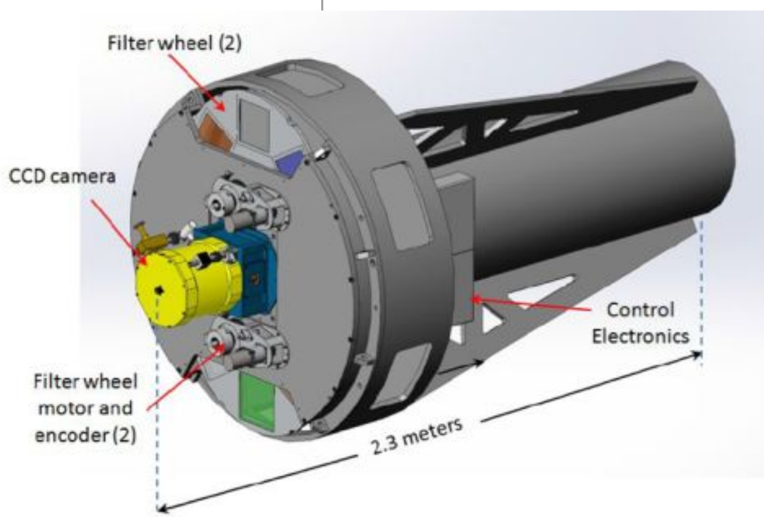
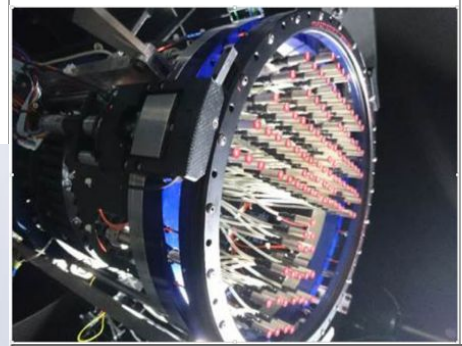
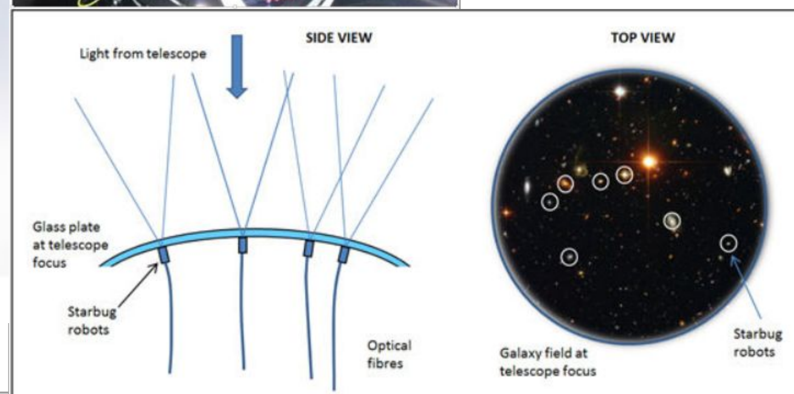


From R. Bernstein

GMT 1st-gen Instrumentation suite

GMACS	G-CLEF	GMTIFS	GMTNIRS
			
Visible MOS	**Visible Echelle**	**Near-IR IFU**	**1-5μm Echelle**
Faint Objects Galaxies Mini-Surveys Transients	Exoplanets Abundances IGM/ISM Stellar Physics	Exoplanets Stellar Outflows Galaxy Dynamics Galactic Center	Exoplanets Pre-main Sequence Proto-stellar Disks Debris Disks

GMT 1st-gen Instrumentation suite

ComCam	MANIFEST
	 
Commissioning	**Fibers positioner**

GMT-TMT combined instrumentation

Table 2. Properties of first-generation instruments and candidates for later instrument development and deployment

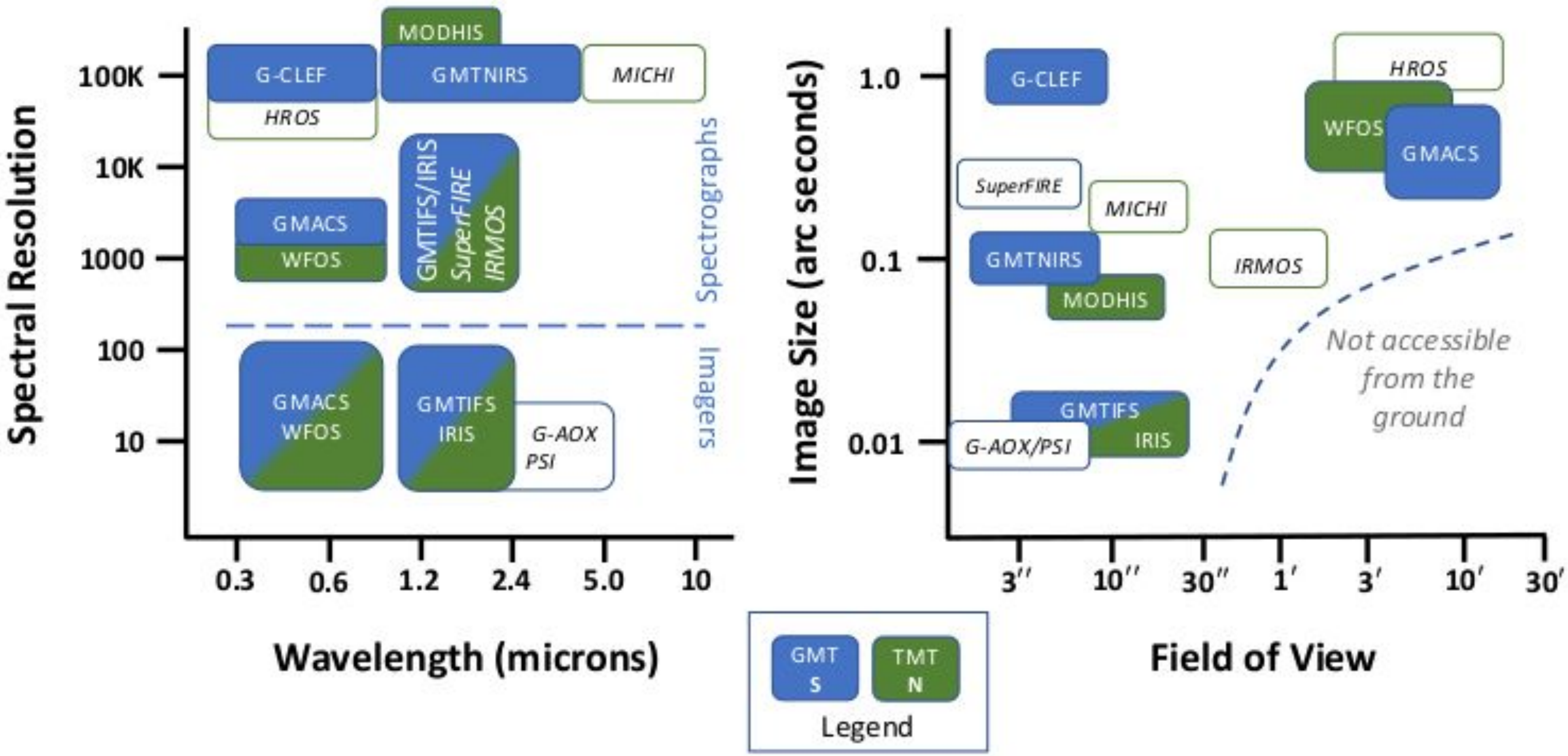
Instruments available within five years of first light				
Instrument	**λλ(μm)**	**λ/δλ**	**FoV**	**Platform**
Multi-Object Imaging Spectrographs				
GMACS[1]	0.31 – 1.0	1,000 – 6,000	7′ x 7′	South/GMT
WFOS[1]	0.31 – 1.0	1,000 – 3,500	5′ x 5′	North/TMT
High Dispersion Spectrographs				
G-CLEF[3]	0.35 – 0.95	50,000 – 200,000	1″ fibers	South/GMT
MODHIS[1]	0.9 – 2.5	100,000	10″	North/TMT
GMTNIRS[2]	1.1 – 5.5	65,000 – 85,000	3″ long slit	South/GMT
Adaptive Optics Fed Integral Spectrographs and Diffraction-Limited Imagers				
IRIS[2]	0.9 – 2.5	4,000 – 10,000	0.5″ - 4″(IFU)/34″	North/TMT
GMTIFS[2]	1.0 – 2.5	5,000 & 10,000	0.5″- 4″(IFU)/20″	South/GMT

Instrument Concepts Under Consideration for Future Development			
Instrument	**Function**	**Instrument**	**Function**
GMag-AOX[1]	High Contrast Imager	SuperFIRE[0]	Near-IR Echelle
PSI[0]	High Contrast Imager	HROS[0]	Visible Echelle
MICHI[1]	Mid-IR Imager/Spec	IRMOS[0]	IR MOS w/IFUs

[0] Pre-Conceptual design [1] Conceptual design [2] Preliminary design [3] Final design phase

From Sidney Wolff

GMT-TMT combined instrumentation



From Sidney Wolff

GMTBrO instrumentation activities

GMTBrO - The GMT Brazil Office

FAPESP joined GMT as a **founding member**.

FAPESP requests three areas of activity: **industry**, **education** and **research**.

The GMTBrO was created to coordinate the Brazilian participation in GMT.

The GMT will be ready by ~2024: to act in its **instrumentation** is a key strategy.

Currently involved institutions with GMTBrO:

- IAG/USP
- IFSC/USP
- IMT (Instituto Mauá de Tecnologia)
- UniVap
- UFABC
- LNA
- UTFPR
- UFMG

GMTBrO instrumentation activities

GMT Brazil Office
FAPESP
GMT

- **ComCam**: SE, SW, Mech
- **GMACS**: SE, Optics, Mech
- **MANIFEST**: SE, Mech
- **GMTNIRS**: SE
- **G-CLEF**: Optics
- **GMT**: Mech, SE

What is Systems Engineering?

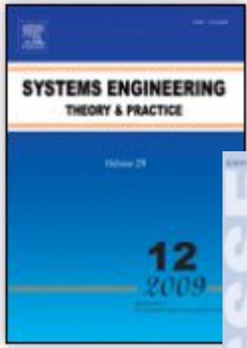
“Systems Engineering is an **interdisciplinary approach and means** to enable the **realization of successful systems**.”

International Council on Systems Engineering (INCOSE)

“Systems engineering is an **interdisciplinary field** of engineering and engineering management **that focuses on how to design and manage complex systems** over their life cycles.”

Wikipedia

SE is a science itself



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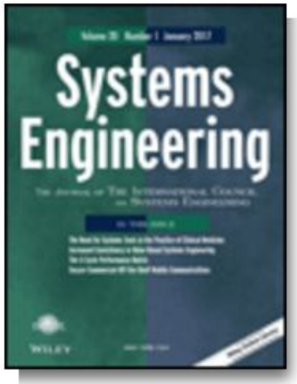

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Previous Issue

Systems Engineering for the Preliminary Design of the Thirty Meter Telescope

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MBSE in Telescope Modeling

Robert Karban, rkarban@incose.org; **Rudolf Hauber,** rudolf.hauber@hood-group.com; **and Tim Weilkiens,** tim.weilkiens@incose.org

In the framework of INCOSE's strategic initiative, the *Systems Engineering Vision 2020*, one of the main areas of focus is model-based systems engineering. In keeping with this emphasis, the European Southern Observatory (ESO; http://www.eso.org/) is collaborating with the German Chapter of INCOSE (http://www.gfse.de/) in the form of an "MBSE Challenge" team. The team's task is to

INCOSE

- INCOSE HANDBOOK

Fonte: INCOSE Handbook (2015)

Technical Processes

1. Business or Mission Analysis
2. Stakeholder Needs & Requirements Definition
3. System Requirements Definition
4. Architecture Definition
5. Design Definition
6. System Analysis
7. Implementation
8. Integration
9. Verification
10. Transition
11. Validation
12. Operation
13. Maintenance
14. Disposal

Organizational Project-Enabling Processes

1. Life Cycle Model Management
2. Infrastructure Management
3. Portfolio Management
4. Human Resource Management
5. Quality Management Process
6. Knowledge Management

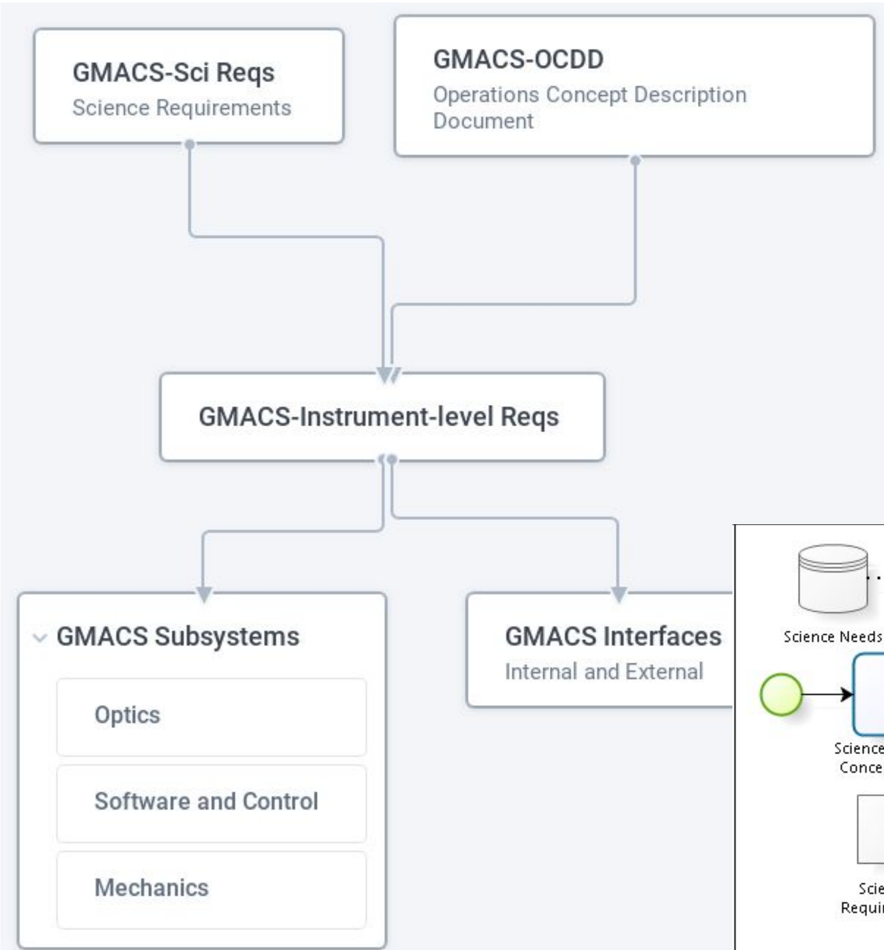
Agreement Processes

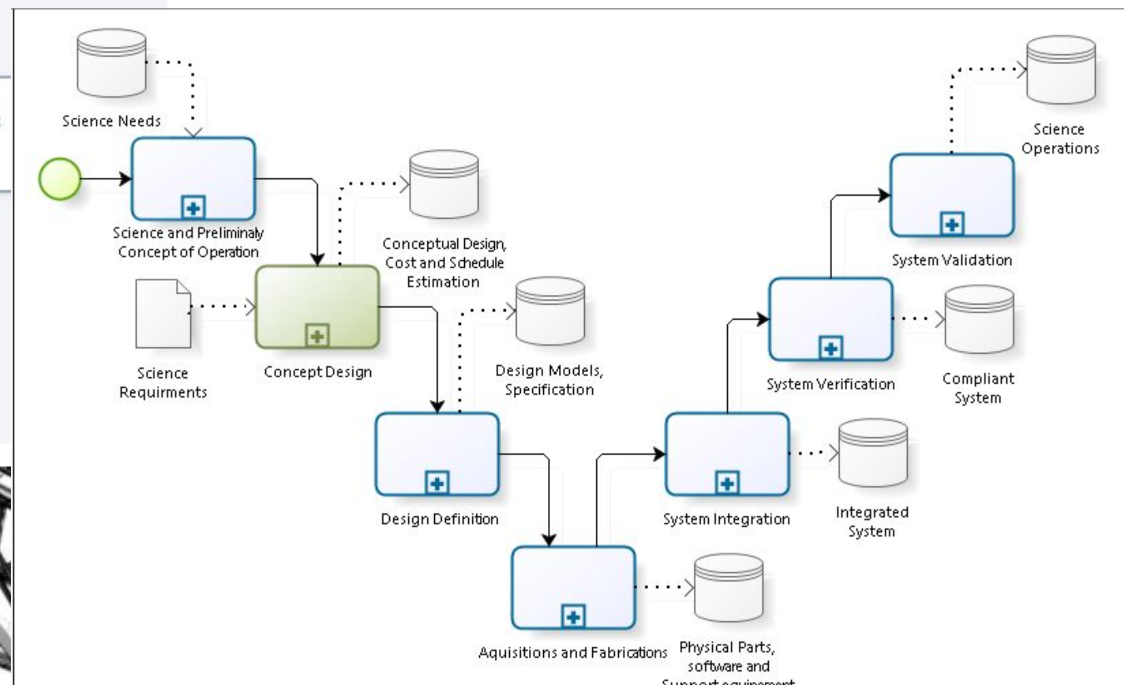
1. Acquisition
2. Supply

Technical Management Processes

1. Project Planning
2. Project Assessment and Control
3. Decision Management
4. Risk Management
5. Configuration Management
6. Information Management
7. Measurement
8. Quality Assurance

SE processes for GMACS





IAG/USP Optics Lab -- SAMplus for SOAR

The concept of the SOAR Adaptive Module (SAM) was developed in 2003, and commissioned in 2013. It was based on AO technology developed in the middle of 1990-s.

The project consists of upgrading the key AO components by new ones:

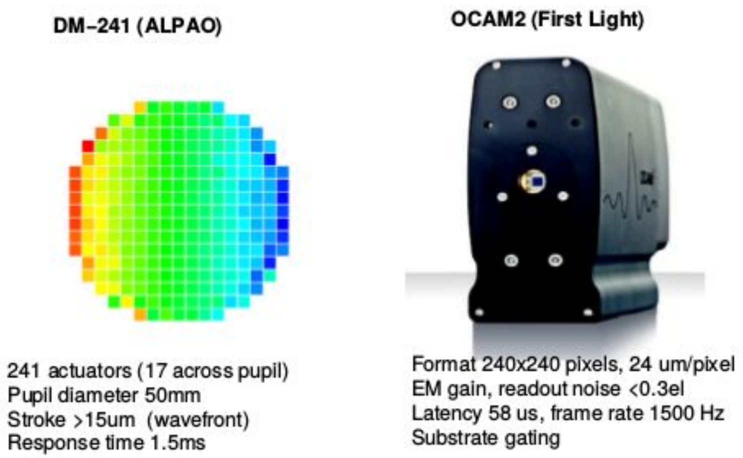
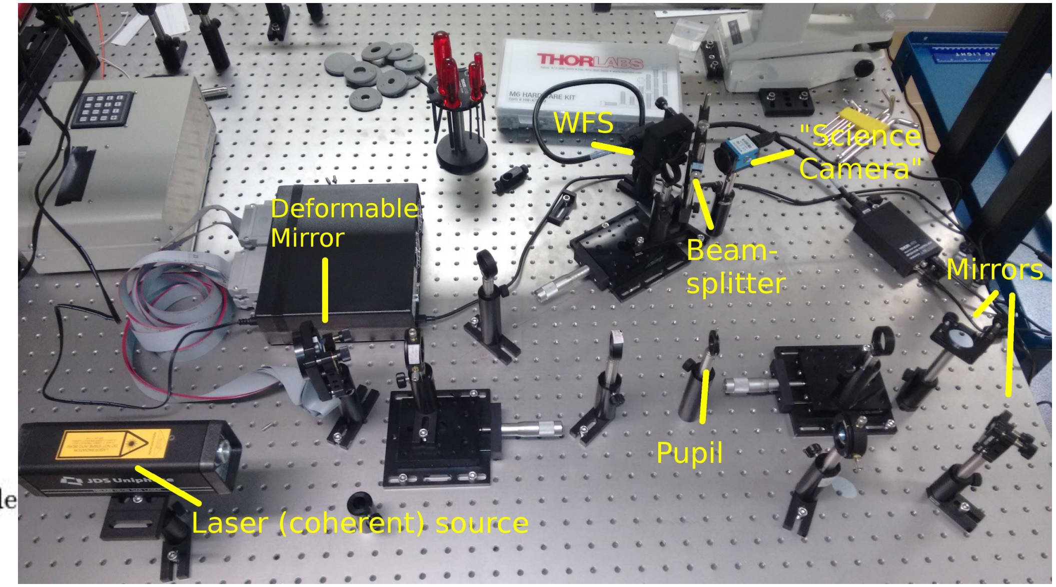


Figure 1: Critical AO components of the proposed SAM upgrade



Why instrumentation

- Scientific experiments become increasingly complex and involve multiple areas of knowledge.
- The largest astronomical research centers have instrumentation/engineering teams.
- The construction of instruments allows to:
    - **design specific instruments** for the research of the institution;
    - have **priority access** to data;
    - access to **telescope time**;
    - ease of **non-standard** instrument **settings**,
    - ***etc***.
- There is already a history of technological innovation in scientific projects (e.g., Simon Ramon medals, ESO 1990 NTT - Kavli Prize 2010, …)

Final remarks

Final remarks

- Recent results and coming facilities make the 2020's a very exciting era for astrophysical research
- The ELTs are the next generation of optical/IR telescopes, and the GMT is one of them.
- FAPESP is a founding member of GMT with a shared of 4%.
- There is an unique space for discovery with the ELTs, mainly with spectroscopy of faint targets.
- GMTBrO coordinates national participation in GMT project, with the goal of a intrunstrumentation team.
- Adaptive Optics is a mandatory technology for large telescopes.
- SE is a powerful method to develop complex systems.
- After years used in space astronomy, SE is reaching the ground-based one.
- Instrumentation development enhances research.

To be an astronomer

How you thought it would be:

How your parents think it is:

How people think it is:

How it really is: